Some aspects of the Biology, Ecology and Control of Slugs in S.E. Scotland with particular reference to the Potato Crop.

By

Adrian Peter Warley B.Sc.

A thesis submitted for
the degree of
Doctor of Philosophy
University of Edinburgh
January 1970

ABSTRACT

1) Methods of soil sampling and slug extraction from samples were developed, which enabled a large number of sample units to be rapidly examined.

2) Estimates were made of slug population densities at field and crop sites from soil sample and trap counts. Numerical ranges are suggested for High, Medium and Low adult populations.

3) Indirect methods of population estimation were compared with the soil sampling method to demonstrate that in some cases the former can be used to give an approximate estimate of slug density and distribution of sufficient accuracy for practical advisory purposes.

4) The nature of slug population distribution on grassland, arable land and potato crops was analysed, with brief investigations into some of the factors affecting numbers, including vegetative cover, soil type, cultivations and predation by Carabid beetles.

5) An assessment of the seasonal population fluctuations and life cycles of the three important slug pest species in the region was made from routine soil sample data.

6) Field trials and laboratory studies on the susceptibility of six maincrop potato varieties were carried out and reasons suggested for the differences, with a brief analysis of the economic implications.

7) A study was made of the following factors influencing crop damage:- slug species, slug maturity, cultivations and crop husbandry including planting depth and early versus late haulm removal, and soil moisture-soil type, for its effect on slug movement in the crop. A close examination of the ridge environment of potato crops was made.

8) Trials on the control of potato tuber damage using surface poison-bait pellets were carried out on susceptible crops, to determine their efficacy in the growing crop and the optimum timing of such measures, with a brief comment on the economic aspects. Laboratory tests were carried out with formaldehyde sprays and granular preparations of the molluscicides metaldehyde and 'Temik' (2-methyl-2-methylthio) propionaldehyde-O-(methylcarbamoyl) oxime.

Acknowledgements

I am very grateful to the Potato Marketing Board for financing this investigation and to Professor S.J. Watson, former Dean of the East of Scotland College of Agriculture for the facilities provided.

I would like to thank Dr. W.J. Guild for his supervision of this work, Dr. P. Osborne, Mr. E. Dunn and Mr. K. Simpson for their interest, the technical staff of the Department of Agricultural Zoology for their assistance and Mr. G. Shukla for help with the statistical analyses.

Method of Presentation

The first part is a review of the literature and an introduction to the experimental work. The experimental work is divided into six sections, each of which is presented under the two main headings 1) Methods and Materials and 2) Results and Discussion, with an initial introduction and in some sections a final general discussion. The final part is a bibliography and supporting work plus supplementary and lengthy data are given in the Appendices.

Contents

List of Figures

List of Plates

List of Tables

INTRODUCTION AND REVIEW OF LITERATURE

Economic Effects

Slug damage to potato crops occurs in most counties of Britain and has been a problem for many years, varying in importance from place to place and year to year.

Cameron (1939) recorded that losses of between one and four tons of potatoes per acre were not uncommon in Scotland. At an average price of £15 per ton of ware this represents a loss of between £15 and £60 per acre. Baker and Waines (1957), showed than an estimated 2,600 tons of ware crop were damaged in 1954, none damaged in 1955 and 1,900 tons in 1956. They estimated that gross slug damage in England and Wales accounts for about 6.7% of the crop in a normal year.

Estimation of Slug Population Density

i) Absolute Estimates. Barnes and Weil (1944, 1945) and Hunter (1966) found that night-search estimates fail to give a correct, representative, species estimate of a slug population and that small slugs were easily missed.

Thomas (1944) concluded that 4" soil sample cores were unsuitable, as many slugs were squashed during sampling; Van den Bruel and Moens (1958) found hand sorting of soil samples to be the most reliable of a number of methods but laborious, whilst both Thomas, and Howitt (1961) concluded that hand sorting of soil samples was subject to considerable error. South (1964) compared the searching of the grass surface of twelve 1 sq.ft. turf samples with slugs recovered from a similar 4" deep turf sample by soil washing, and found that there were significantly more ($P > 0.05$) in the latter. He also found that the dry sieving and hand sorting of turves failed to recover small slugs (<100 mg).

The most accurate absolute method of slug population estimation was devised by South. He dug soil samples from fixed sampling positions on grass and arable fields, using the centric-systematic method of Milne (1959). The samples were subjected to progressive flooding by cold water over 12-13 days. He found that 99% and 94% of the Agriolimax reticulatus (Müller), 81% and 50% of the Arion intermedius (Normand), and 94% and 80% of the Arion fasciatus (Nilson) were recovered from the two types of sample. South (1964) used the soil washing-flotation method of Salt and Hollick (1944) (modified by Raw (1951)) as a standard check method and obtained over 98% recovery of marked, introduced newly hatched slugs and eggs of the species A. reticulatus.

Hunter (1966) used a modification of South's flooding process to recover slugs of the species A. reticulatus, Arion hortensis (Férussac) and Milax budapestensis (Hazay) from 12" deep, one foot square turf samples and arable soil samples. He found the recovery efficiency to be somewhat less than that described by South, and recovered no eggs by it. He also found that the eggs of A. hortensis broke up easily during soil washing, whilst the weight loss of individual slugs was considerable and thus the method was unsuitable for obtaining accurate weight records of slugs.

The mark, release and recapture method was used by Hunter, and Newell (1965) to estimate population densities of A. reticulatus and A. hortensis on a part-field scale. Hunter (1968a) showed that the mark, release and recapture method tended to under-estimate the slug populations, especially that of A. hortensis, probably because small slugs tend to be missed in both capture and recapture. He found that this method had the disadvantage that it was a lengthier process than soil sampling and failed to give a representative age distribution of the population, necessary for life-history studies.

Newell (1965) carried out two mark, release and recapture experiments with A. reticulatus, marked with the radio-nucleide P 32. He stated that although wide fiducial intervals, at the 95% level, were implicit in the estimates, they did give some indication of the population and the accuracy of the estimate.

ii) Relative Estimates. Miles, et al (1931) concluded that the number of slugs trapped under boards and sacks were merely a direct response to weather conditions.

Thomas (1944) found the effective trapping area of inverted turves to be between 3.5 and 4.5 feet for *A. reticulatus*. South (1964) and Hunter (1968a) compared the number of slugs caught under 'Marley' tiles and sacks with slugs recovered from 1 ft. sq. soil samples. They concluded that the method was less reliable than soil sampling.

Howitt (1961) used inverted wooden boxes, laid on the ground, to estimate slug numbers. Barnes and Weil (1942) recorded numbers caught by several baits including metaldehyde-bran baits and Barnes and Weil (1944, 1945), Barnes and Stokes (1951), Barnes (1953), Thomas (1944, 1948) all estimated the numbers active on the soil surface by meta-bait catches within a fixed sampling time. Thomas (1944) estimated field populations using a standard meta-bran bait placed under black painted glass squares, 6" x 6". The method was used principally to compare the efficiency of field-control measures, using the premise that providing weather conditions are equal over the area, then an equal proportion of the slug population should be active over the total area.

Van den Bruel and Moens (1958) compared numbers trapped by D.N.O.C. and metaldehyde with the surface-searching and hand-sorting of soil samples, and they (like Webley (1962))demonstrated that metaldehyde baits have a differential attraction for different species, the species *A. hortensis* showing considerably less attraction to the baits. Webley (1963) used metaldehyde bait for the comparison of slug populations on a three year old sainfoin plot and a fallow marketgardened plot and found:-

1) that more slugs were trapped with exposed baits (possibly because of the desiccating action of the air),

2) higher catches under black than clear glass covered baits (due to the behaviour of A. hortensis),

3) no increased catch by the addition of alum or insecticides to the meta-baits.

Predominantly more A. reticulatus were trapped on the fallow plot and more A. hortensis and A. fasciatus on the sainfoin plot. Webley suggested that the population of A. hortensis increases on undisturbed ground and is at its lowest on disturbed arable ground.

In further meta-bait trapping experiments Webley (1964, 1965) found by applying regression analysis, that meteorological factors accounted for 72% of the catch variance, 16% of the remainder being due to the fall off in biscuit efficiency with length of exposure. The remaining 12% of the variation was caused by the effects induced by different species and seasonal differences in their biology. Webley showed that an area can be repopulated within seven nights after a trapping period and showed that slugs are caught from within a radius of 3-4 feet by meta-bait traps. Gould (1962) estimated the effect of field-control measures on a cereal crop by counting dead slugs in twenty quadrats, each of 1 sq.ft.

iii) Population Indices. Miles et al (1931) tested the effectiveness of molluscicides applied to brassica crops by measuring the decrease in damage to the plants. Duthoit (1961, 1963) devised a method for assessing the feeding potential, of slugs on newly-sown winter wheat crops, in order to forecast damage to the germinating seeds. However, Newell (1965) found this method to be unreliable in field tests and Hunter (1968b) carried out tests on the influence of various environmental and species factors on damage to wheat grains. Both concluded that it was impossible to relate the amount of damage to slug numbers or to slug species since an unknown feeding and species behaviour factor was involved.

Trought and Heath (1963) used 1" discs of cabbage leaf, placed under cardboard squares, to assess the control effect of molluscicide treatments. Newell (1965) carried out a field experiment in order to relate numbers to feeding activity, using the cabbage disc and wheat grain methods. He found the former a more reliable index to slug feeding activity since the mean area of leaf eaten is obtained, a measure independent of feeding behaviour. In a field experiment Newell found that a population of under 0.5 slugs per square foot (*A. reticulatus* only estimated) ate approximately 12% of the leaf disc area and 22% of the wheat grains over nine nights in November 1963 on a barley stubble. He did not find the leaf discs to be damaged by other soil animals but suggested that the damage to the leaf discs would depend very largely on the availability of an alternative food supply in the field.

Population Distribution and Treatment of Data

As well as vertical distribution there are three basic types of horizontal distribution which are:-

1) Random : 2) Contagious : 3) Regular.

A regular distribution is not very likely to occur in nature. Most random populations are described by the Poisson distribution series. The plotted curve of this series is described completely by one parameter, since the variance (S^2) is equal to the mean ($\bar{x}$) (Finney, 1946). Very rarely is the variance less than the mean for animal population samples, which implies a more regular (uniform or even) distribution than is described by a Poisson series.

Most commonly in ecological studies the variance is found to be larger than the mean, that is, the distribution is contagious, the population being clumped or aggregated. Many contagious insect populations that have been studied have been adequately represented by the Negative binomial distribution (Southwood 1966). This distribution is described by two parameters, the mean ($\bar{x}$) and the exponent 'k', which is a measure of the amount of clumping or aggregation and is often referred to as the 'dispersion parameter'. In most instances, values of 'k' are about 2.0. As they become larger the distribution approaches and is eventually identical with that of the Poisson, whilst fractional values of 'k' lead into the logarithmic series, expressing a more regular non-random distribution. The smaller the value of 'k', the greater the degree of aggregation.

The value of 'k' is not constant for a population, and often increases with the mean (Anscombe, 1949; Bliss and Owen, 1958). A value of 'k' can be calculated by several approximate and accurate methods. Where samples are taken from different sites (each of which may have a separate 'k') a common value of 'k' can be calculated which is useful for transforming data for an analysis of variance between treatment effects in trials and experiments. After fitting the value of 'k' to the data the agreement between the negative binomial (and Poisson) series as a model can be tested by comparing the expected frequencies of each value (calculated) with the actual values, by a Chi squared goodness of fit test (Bliss and Fisher, 1953).

Webley (1962, 1963, 1964, 1965) used the transformation of $\sqrt{n + 0.5}$ which is appropriate to a random, Poisson distribution, in order to investigate slug catches by metaldehyde baits. South (1965) found from sample counts that the standard deviation was proportional to the mean and used a transformation of log (n + 1). Both South (1964) and Hunter (1966) investigated the distribution of slugs by means of the 'coefficient of dispersion' parameter (first used by

Blackman 1942 and from which Milne (1959) calculated expected coefficients for a randomly dispersed population. South (1964) found that on grassland there was a strong element of aggregation for the species A. reticulatus, A. fasciatus and A. intermedius. He found A. reticulatus to be aggregated on grassland with respect to areas of about 3 in^2 and 1 $ft.^2$, and that inconclusive evidence from arable samples indicated less aggregation.

South (1964) found no difference in the degree of aggregation between immature and mature slugs of the three species studied. He also showed that the frequency distribution of his sample data displayed close agreement with the negative binomial distribution.

Hunter (1966) also showed that a significant proportion of routine samples containing A. reticulatus, A. hortensis and M. budapestensis were aggregated with high coefficients for A. reticulatus in August, late June for A. hortensis and early June for M. budapestensis which coincided with the hatching of slugs from egg batches. He attributed other aggregations throughout the year to clumping at food and shelter sites.

Newell (1965) compared the frequency distributions of trapped slug (A. reticulatus only) samples (from two mark release and recapture experiments on two stubble fields) with the expected Poisson and Negative-binomial distributions. He showed that both mature and immature A. reticulatus were overdispersed or aggregated.

Life Cycles of Slugs

Barnes and Weil (1944 and 1945) and Barnes (1944 and 1953) found from night collections that a slug species reached its greatest numbers at a particular season each year and that the weight of each species was greatest soon after peak numbers were found. Bett (1960) made observations on slug life cycles from recorded weight data of collected slugs and the state of their genitalia. Hunter (1966) stated however that such data is probably unreliable since trapping tends to overestimate the proportion of large slugs in a population and he gives more detailed information on slug life cycles from the examination of slugs in routine monthly soil samples.

The Varietal Susceptibility of Potatoes

Investigations made by Gould (1965) in the 1964 National Institute of Agricultural Botany Potato Variety trials in Norfolk showed differences in the percentage of tubers damaged between some varieties. However, these trials were not laid down with this specific object in view and the size and shape of the plots and the number of replications (4) were not sufficient, in the author's opinion, for satisfactory comparisons, when slugs are known to exhibit aggregation and 'patchiness' of distribution. Thomas (1947) conducted tuber sampling investigations on a small plot of three potato varieties, Arran Banner, Arran Peak and Majestic, and showed differences in susceptibility to slug attack. Whilst he used a larger block design than that used by the N.I.A.B. with larger guard areas, in order to eliminate any possibility of counter-attraction there was only one replicate of each variety and only two plants per variety were examined on each of the six sampling dates. Thomas suggested some association between the timing of slug attack and tuber maturity. Apart from this suggestion there have been no other explanations for these apparent differences in susceptibility.

Factors Influencing Crop Damage

i) Slug Pest Species. Carrick (1938) reported that the main slug pest on potatoes in S.E. Scotland was *A. reticulatus* and to a lesser and more localised extent *A. fasciatus*. He found *A. hortensis* to be relatively uncommon, and not a pest on potatoes. Thomas (1947) reported that A. hortensis and Milax slug species were mainly responsible for primary damage to potato tubers in South East England, whilst pot experiments showed that A. reticulatus and A. fasciatus rarely bored through the perfectly healthy skin of tubers. Edwards and Heath (1964) and Stephenson (1964) have stated that A. reticulatus does not attack potatoes. Stephenson (1967) considered the species A. hortensis and M. budapestensis to be the most important slug pests on the potato crop in the South of England, and that slug damage only follows mechanical damage caused during growth or by other soil organisms.

With reference to the nature of the tuber damage, Carrick (1938) stated that A. reticulatus only makes a small entrance hole in the tuber skin with the result that badly tunnelled potatoes may show little outward sign of damage. However, damage caused by A. fasciatus was more obvious, large portions of the tuber surface being removed. He also observed that the former species rarely remains inside the excavated tunnel whereas the latter species often remains inside for days until a large cavity has been formed. Thus in the case of infestation by A. fasciatus, damage to individual tubers is always more extensive.

ii) Slug Maturity. To the author's knowledge there has been no reference by previous workers as to the size or maturity of slugs causing tuber damage. Guild and Evans (personal communication) have however observed very young slugs in damaged tubers. It would seem obvious that the larger full grown slugs of the species involved are responsible for the majority of tuber damage but to what extent juvenile slugs can cause or contribute to tuber damage is not clear. Both young and adult slug generations of the three main species involved in this region are present in the autumn on potato crops.

iii) Rainfall, Soil Moisture and Soil Type. In dry seasons tuber damage is apparently markedly reduced (see 1955 estimate of Baker and Waines; and Carrick, 1936). Thomas (1947) suggested that slugs became more active with the onset of the autumn rains and Stephenson (1967) suggests that slugs are only able to move into the ridge, after haulm removal has permitted increased wetting of the ridge soil. Carrick (1936) pointed out that in the autumn there are an increasing number of wet and windy nights which slugs avoid by remaining underground and hence feed longer on the tubers.

Carrick (1938),and Baker and Waines concluded that high slug infestations are associated with the high moisture holding capacity of the heavier clay soils and those of high organic matter content. Whether this was due entirely to a higher population of slugs, or to a particularly dominant pest species supported by these higher moisture-retaining soils or, also to the cloddy structure of the soil permitting greater access to the tubers in the ridge, is not clear. Carrick (1936, 1942) found little relation between soil acidity and the occurrence and abundance of slugs.

iv) Cultural and Crop Husbandry Practices. Carrick (1936) suggested that the practice of applying farmyard manure to stubble fields over the autumn and winter greatly aided slug survival and population growth and that tuber attack is negligible before late September when the surface vegetation dies off and slugs turn to the tubers as an alternative food supply. Hunter (1967) showed that repeated cultivations can reduce slug populations and suggested that slugs may become increasingly serious pests as cultivations become less necessary to growing crops (increased use of herbicides).

Baker and Waines (1957) found from Potato Marketing Board crop checks, that whereas over 9% of crops on the arable acreage were slug infested, only 2.5%

of newly-broken grassland was infested in Scotland and the difference was less distinct in England and Wales.

Gould (1961) concluded from his survey of 130 crops preceding main crop potatoes in 1961, that few conclusions can be drawn from the information on previous cropping. He suggested that slug populations are probably affected by the summer conditions during cropping and these may be more important than the previous crop in the case of potatoes. Stephenson (1965) found that irrigated crops of Redskin and Majestic suffered greater damage than those not irrigated.

Chemical Control of Slugs

The only commercially available molluscicides which are effective against slugs to date are still based on metaldehyde (with the recent exception of the carbamate 3,5-dimethyl-4-methylmercapto-phenyl N-methylcarbamate, 'Mesurol' - Bayer). These include the metaldehyde-bran pellet, containing up to 8% metaldehyde, and metaldehyde sprays. These products are used more widely on the garden-horticultural scale as they are expensive. Many workers have experimented with different metaldehyde concentrations and different foodstuff and chemical additives in an attempt to produce a more attractive, lethal and persistent bait since the discovery of the molluscicidal properties of metaldehyde. The first reference to its use in this country was made by N.G. Hadden (1936) in the 'Gardening Illustrated'. Esslemont (1938) obtained good kills by broadcasting a mixture of one part metaldehyde to sixteen parts sand at a rate of $1\frac{1}{2}$-2 cwts per acre. Gimmingham and Newton (1937) conducted numerous small plot trials with mixtures of metaldehyde and bran, the best results being obtained with a mixture of 4 grams of metaldehyde to 8 oz of bran. Lange and Macleod (1941) used bait preparations incorporating 1.5 - 2.5% powdered metaldehyde and 5% calcium arsenate and caseinate. Five other aldehydes were tested but none showed molluscicidal properties. Barnes and Weil (1942) carried out extensive trials with various concentrations of metaldehyde with many foodstuff substitutes. Thomas (1948) recommended the use of a more durable biscuit type of bait consisting of one part metaldehyde to thirty parts bran with molasses and casein-glue. Cragg and Vincent (1952) discovered the contact nerve poison effect of metaldehyde as well as the anaesthetic stomach poison effect and suggested the use of metaldehyde sprays. Moreton (1953) tested various sprays consisting of metaldehyde suspensions in water. He obtained good slug kills by the application of 100 gallons per acre of 0.5% metaldehyde solutions (2.5 lb metaldehyde per acre) though the costs were too high for agricultural use. Ruppel (1959) tested the effectiveness of the insecticide Sevin (1 Napthyl-N-methylcarbamate) alone, and together with metaldehyde.

Howitt (1960) suggested the incorporation of metaldehyde in spray applications of the fungicide 'Captan' on horticultural crops as both substances were compatible. The most recent work on the application and effective use of metaldehyde-bran pellet and biscuit preparations has been conducted by Webley (1962, 1963, 1964 and 1965). He showed that the addition of one part of 30% 'Sevin' to forty parts of a metaldehyde-bran mixture gave an improved kill and suggested that metaldehyde sprays give a better control of epidemic outbreaks whilst the baits are more useful for keeping populations at a low level.

Other chemicals used include Aluminium sulphate; which Hodson (1924, 1925) used in spray applications of 1 lb aluminium sulphate in 5 gallons of water saturated with lime and dry applications of one part Aluminium sulphate and two parts of lime, broadcast at ½ cwt per acre which gave an estimated 70-80% slug kill. However, this was again too expensive for agricultural use. He also found Sodium fluoride to have good molluscicidal properties. Esslemont

(1938) and Cameron (1939) obtained promising results with repeated applications of lime, either alone or mixed with aluminium sulphate and copper sulphate either alone or in combination with Kainit (1 part copper sulphate to 20 parts Kainit, 3 cwts per acre) though they realised that the success of these surface applications depended largely on slug activity on the soil surface. They pointed out that such repeated applications are costly and uneconomical.

Hunter, Freytag and Ritchie (1952) tested a range of phenolic compounds as potential molluscicides. These compounds included 90% 2,4,6-trichlorphenol, 75% sodium pentachlorophenate and 13% sodium salts of other chlorophenols, 2,4,5-trichlophenol, and copper pentachlorophenate. Batte and Swanson (1952) also tested phenolic compounds in the laboratory, these included pentachlorophenol, 2,4-dinitro-6-phenylphenol and dinitro-O-cyclohexylphenol; 100% mortalities were obtained after 24 hours, using concentrations of one part per million. They found that apparently the toxicity of the chlorophenol compound is directly proportional to the degree of chlorination of the phenol radical; whereas the addition of sodium or copper salts decreased activity. Ruppel (1959) tested a small range of carbamate compounds which included 'Isolan', 'Pyrolan' and G34-(1-ethyl-3-methylparasolyl-(5) dimethyl carbamate) all of which were effective against the garden snail Helix aspera (Müller). Stephenson (1959) noted that the application of Aldrin dusts before the planting of Majestic potatoes produced a significant (5%) reduction in slug damage to the tubers. Conversely, Jones (1965) found that greater applications of Aldrin to a carrot crop coincided with heavier slug damage on those plots. Howitt (1961) found calcium cyanamide and some amine salts to be effective molluscicides. Gould (1962) obtained some degree of control of A. reticulatus on freshly sown cereal crops, with seed dressings of copper oxychloride though they failed to reduce damage to the germinating shoots. Wain (1963) found 'Ioxynil' (3:5-diiodo-4-hydroxybenzonitrile) to have molluscicidal properties ten times greater than metaldehyde. Unfortunately the compound has no residuality and is neutralised immediately on contact with soil.

Trought and Heath (1963) discovered that the fungicide triphenyltin hydroxide has molluscicidal properties when used as foliar sprays with concentrations up to 500 ppm and bran baits containing 0.5% of the compound. Crowell (1967) confirmed the fact that all established chlorinated hydrocarbon and organo phosphate pesticides tested have shown little or no toxicity to slugs and snails. He carried out 14 day tests with carbamates on Arion ater (L) and H. aspera. The carbamates were Bayer 37344 (4-methylthio)-3,5-xylyl methylcarbamate), UC20047A (Tranid(R) (exo-(5-chloro-6-oxo-endo-2-norbornane carbonitrile O-(methylcarbamoyl) oxime, EP-332 (M/¯ /¯ (dimethylamino)methylene/amino/phenyl carbamate hydrochloride), EP-316 (m-cym-5-ylmethylcarbamate)oxylthioacetimidate). Crowell suggested that the effectiveness of a given carbamate bait is governed to a considerable extent by the quantity consumed before paralysis sets in, there being a more or less ideal balance between the concentration which would produce a sublethal dose and that which would be repellent. The first workers to discover the acute toxic effect of a carbamate (Bayer 37344) on molluscs were Getzin and Cole, 1964, and Getzin 1965.

Introduction to Experimental Work

The experimental work,which is the subject of this Thesis was designed to gain more knowledge of 1) the factors involved in determining the incidence and severity of slug damage to potato crops; 2) the biology and ecology of the slug species responsible and 3) the economic effects of damage and the efficacy of control measures in the crop.

The work will be considered separately in the following six sections.

A. Estimation of Slug Population Density in the Field. The assessment of field populations by soil sampling on field and trial sites and a comparison of different indirect methods with the aim of evolving a field technique for practical use by growers and advisors.

B. The Spatial Distribution of Slugs. The analysis of soil sample and trapping data to determine the type of distribution in different agricultural field situations and some factors influencing distribution and density.

C. Seasonal Population Fluctuations and Life Cycle Studies of the Slug Pest Species. An examination of the seasonal population fluctuations of the slug species A. reticulatus, A. hortensis and A. fasciatus from routine soil-sample data.

D. Susceptibility of Different Potato Varieties. Field trials and laboratory tests on slug damage to different potato varieties.

E. Some Factors Affecting Crop Damage. The examination of some environmental and biological factors influencing potato tuber damage from the field trials and observations and laboratory experiments.

F. The Control of Slugs and Tuber Damage. Field trials with bait pellets on the control of slugs and the reduction of damage to susceptible potato crops; and the laboratory evaluation of two molluscicidal compounds and a new granular formulation of metaldehyde plus 'Sevin' (insecticide).

Sites of Field Trials and Investigations

In the course of the present studies, the more important field investigations and trials were carried out at the following sites:-

1) Bush Estate. Edinburgh Centre of Rural Economy Midlothian, Map ref. 24.4E, 63.5N Ordinance Survey Sheet No. 62.

The estate is situated at 500 ft above sea level to the East of the Pentland Hills. Although the site was probably not climatically typical of the main potato growing areas in S.E. Scotland (being approximately 300 ft higher than these areas), it was chosen for its availability, the fact that good crops of potatoes are grown there regularly and because the three main pest species of slugs found in infested potato fields were present in sufficient numbers for study.

Investigations on population fluctuation and life cycles of the three slug species were made on a grass plot that had been in rough self sown grass for six years. The shallow (12 in.) well drained top soil of fluvio-glacial sand and gravel (Darvel series) supported a flora consisting mainly of <u>Holcus mollis</u> (L), <u>Festuca pratensis</u> (L) and clumps of <u>Dactylis glomerata</u> (L) and <u>Rumex acetosella</u> (L) with a considerable amount of soil surface moss in places. The grass plot (Fig. 1A Appexndix A), measuring 50 ft x 50 ft was marked off into 16, 4ft x 4ft square plots with an overall one yard wide outer guard area. Each plot was regarded as a single sampling station for soil sampling and the comparison of indirect trapping methods.

2) <u>Langhill Farm</u>. Edinburgh Centre of Rural Economy, Midlothian. Map ref. 27.7E, 64.3N Ordinance Survey Sheet No. 62.

The farm is situated 500 ft above sea level. A potato variety trial and a bait pellet control trial were carried out in 1967 in Laundry Field, an 11 acre field, cropped with Redskins in 1967 (after two barley crops). The soil type was variable, ranging from the lighter fluvio-glacial sand and gravel loams (Darvel series) to the heavier Macmerry and Winton series.

3) <u>Saltcoats Farm</u>. Gullane, East Lothian. Map ref. 48.5E, 82.3N Ordinance Survey Sheet No. 62.

The farm is situated at sea level, immediately to the landward of coastal sand dunes. A bait pellet control trial was conducted (1966) on a Redskin crop grown on a sandy clay loam soil (Macmerry series).

4) Highfield Farm. North Berwick, East Lothian. Map ref. 54.5E, 83.0N, Ordinance Survey Sheet No. 63.

The farm is situated 200ft above sea level on stony boulder clay loam (phase of Kilmarnock series). Bait pellet control investigations were made on a crop of King Edwards in the autumn of 1966.

5) Gateside Farm. Linlithgow, West Lothian. Map ref. 04.9E, 75.7N, Ordinance Survey Sheet No. 61.

A variety trial was carried out on a field of heavy clay soil (dark series of Winton series) which has imperfect drainage with soil moisture above field capacity after moderate rain.

6) Beanston Mains and Beanston Garden Farms, near Haddington, East Lothian. Map ref. 55.7E, 77.1N, Ordinance Survey Sheet No. 63.

The following investigations were carried out on the sandy clay loam soil (Kilmarnock series) on the two farms in 1967 and 1968.

i) Variety Trial

ii) Bait Pellet Control Trials on two Redskin crops (A + B)

iii) Early versus Late Haulm Removal Experiment - Redskin crop (A)

iv) Slug Population Estimation by

a) Soil sampling alone - Grass Paddock (divided into 24 12 yd x 12 yd sub plots)

b) Soil sampling + trapping comparisons - 1) Redskin Crop (A)

2) 20 acre ploughed field (divided into 36, 50 yd x 50 yd sub plots)

v) Approximate Estimation of Field Distribution by trapping (pellet) Strips

1) 15 acre ploughed field

2) Adjacent crops of winter wheat and spring barley.

Analysis and Treatment of Experimental Data

Only those results having a direct bearing on the investigations are reported in the main text,and supporting plus lengthy data is given in the Appendix.

The following transformations of the raw data were used in the statistical analysis of results:-

1) Slug Counts. For a comparison of treatment effect in the various potato trials, a transformation based on the evidence of the aggregated distribution of slugs (see Section B) was used. In these analyses, only those slugs weighing more than 25 mg were included (termed adult "effective") since smaller slugs were considered to be of no importance in damaging potato tubers (see Section E). All estimates of population density (mean + standard error of the mean) which were calculated from the raw data refer to adult slugs.

2) Slug Eggs The transformation log n was used in order to normalise the distribution (n = number of eggs).

3) Slug Holes (in tubers). The transformation log (n + 1) was used in order to normalise the distribution.

4) Percentage Data. The angular (arcsin) transformation of all percentage data was used.

The statistical significance of results are shown by means of asterisks * thus,

***	=	significant at a probability of 0.01
**	=	" " " " " 0.1
*	=	" " " " " 0.5
and NS	=	not significant at a probability of 0.5

In some tables the following abbreviations are used for convenience:

'R' = <u>A. reticulatus</u>

'H' = <u>A. hortensis</u>

'F' = <u>A. fasciatus</u>.

SECTION A

ESTIMATION OF POPULATION DENSITY

Introduction

It appeared from the literature that only direct soil sampling methods give reliable estimates of the species and age complex of a slug population, suitable for life-cycle studies and reasonably accurate population estimates. However other indirect methods such as trapping by boards and metaldehyde baits and 'damage to trap' estimates may be useful for giving an approximate estimate of slug populations by a relatively quick method. These investigations were aimed primarily at practical field application, and the use of a mark, release and recapture method was thought to be impractical.

In this section, direct estimates by soil sampling at some of the different field and trial sites are described first followed by a comparison of various indirect methods with the former method at three sites.

Direct Soil Sampling

Materials and Methods

Considerable effort was spent in achieving a faster and more convenient method of soil sampling and sample recovery so that a large number of sample units could be taken. The techniques relating to sample type and size, sampling stations and the efficiency of slug recovery from these samples are described in Appendix A.

Population density estimates were made from soil samples taken at the following sites:-

1) Bush - grass plot - 17 monthly 4" deep turf samples (March 1967 - July 1968) each of 16 sample units.

2) Beanston - 3 acre grass paddock - 24, 5" deep turf sample units taken

in June 1968.

3) Beanston - 20 acre ploughed field - 36, 10" deep (in 2 units) sample units taken in April 1968.

4) Beanston - variety trial - 24 plant-soil sample units taken in September 1967.

5) Langhill - variety trial - 60 plant-soil sample units taken in October 1967.

6) Gateside - variety trial - 90 plant-soil sample units taken in two samples in October and November 1967.

7a) Beanston - Early versus Late haulm-removal trial on a crop of Redskins - 48 plant soil sample units.

7b) Beanston - Late pellet-application trial on the same Redskin Crop as above - 36 plant-soil sample units taken in October 1967.

Results and Discussion

The data are presented in three parts:-

1) The more detailed monthly sample data from Bush.

2) Samples from the Ploughed Field and Grass Paddock.

3) Samples from Potato Crops.

The population density estimates, with fiducial intervals at the 95% confidence level, (also expressed as a percentage of the mean) are given in Tables B1 - B8 inclusive in Appendix B.

1) The more detailed monthly sample data from Bush

A. reticulatus

The mean estimate (Table B1) varied between 2.5 and 10.6 per sq.ft. (109 - 463 x 10^3 per acre) over the sampling period. The density was greatest in the winter and spring and lowest in the summer. The fiducial intervals varied greatly from month to month and in general the greater the density, the more accurate the estimate. An average fiducial interval of 44.1% was calculated from the 16 samples. In only five samples did the fiducial interval exceed 50% of the mean.

A. hortensis

The mean density (Table B2) varied between 0.8 and 8.0 per sq.ft. (33 - 349 x 10^3 per acre). The density was greatest in the winter and spring and lowest in the summer. The variation in the fiducial interval showed again that the accuracy of the estimate varied greatly from month to month but was on average (57.1%) lower than that for A. reticulatus.

A. fasciatus

There were more adult slugs in late winter and early spring and least in the summer (Table B3). The mean density varied between 0.1 and 3.8 per sq.ft. (5.4 - 164.0 x 10^3 per acre) over the sampling period. The accuracy of the monthly estimate again varied greatly and was on the average (64.1%) lower than for the two other species.

Total of the three species

The mean monthly estimate (Table B4) varied between 3.1 and 22.1 slugs per sq.ft. (136 - 963 x 10^3 per acre) over the sampling period. The highest population density occurred in the winter and spring months (February - May) and the lowest in the summer and early autumn months (July - November). The accuracy of the estimate of the mean varied greatly (7.5% - 58.6%) between sampling dates but only in four cases did it exceed 50% of the mean.

2) Samples from the Ploughed Field and Grass Paddock

The accuracy of the estimate (Table B5) of adult A. reticulatus varied considerably at the two sites, 33% and 64%, though the numbers were approximately equal and the distributions very similar (see page 81).

The intensity of sampling on the paddock was also over four times that on the ploughed field.

The estimated density of A. reticulatus at the two sites was equal to the lowest density estimate of slugs made on the Bush plot; at a time of the year when adult populations would appear to be at their peak (Bush Data).

The absence of A. hortensis on the Paddock was noticeable (discussed Page 82 later), and the mean density estimate of this species on the ploughed field was about equal to the lowest recorded at Bush, again at a time when the proportion of adult slugs appeared to be high. The fiducial intervals of the estimate (62.3%) for this species was twice that of A. reticulatus (31.2%); (cf the estimates from Bush).

The numbers of A. fasciatus were so few that estimates were very inaccurate. However, the populations at the two sites appeared to be equal to the lowest recorded at Bush, again at a time when adult populations appear to be high.

3) Samples from Potato Crops

The estimates of slug numbers found next to the tubers in the ridge at the four sites, on the different sampling dates (Table B6) showed the following:-

A. reticulatus

A very low density (0.7 - 1.3 per sq.ft.) on the Beanston and Langhill variety and Beanston Redskin crop/trial sites compared with the two other sites (1.5 - 3.1 per sq.ft.). The mean density on the Gateside trial site (3.0 per sq.ft.) was four times greater than at the Beanston variety trial site (0.7 per sq.ft.).

A. hortensis

The lowest estimate was made at the Langhill variety trial site where there were extremely low numbers (approx. 0.4 per sq.ft.). The greatest mean density estimate was made at Gateside (4.8 - 6.0 per sq.ft.) where numbers approached the highest mean estimate recorded at Bush. The density on the Beanston Redskin crop (3.9 per sq.ft.) was quite high, whereas that on the variety trial (1.4 per sq.ft.) was fairly low.

A. fasciatus

The estimates showed very low numbers at both Beanston sites (0.1 - 0.2 per sq.ft.) and much higher numbers (approximately equal) at the Langhill and Gateside variety trial sites (0.8 - 1.0 per sq.ft.).

Total slugs of the three species

The greatest density of slugs found next to the tubers occurred at Gateside (9.5 - 10.1 per sq.ft.) where there were twice as many slugs per acre of plant - tuber ridge as on the Beanston Redskin crop (5.4 per sq.ft.) and approximately four times the number at the Beanston and Langhill variety trial sites (2.2 - 2.6 per sq.ft.).

Discussion

The investigations show that the density of adult slugs varied considerably from site to site both with regard to the total numbers and the relative numbers of the individual species in each population. The more detailed estimates made at Bush showed that the density varied by as much as four to thirty times over the 17 month sampling period, depending on the species concerned.

Table B8 shows the population estimates of the species A. reticulatus and A. hortensis made by other workers on different types of field sites. With the exception possibly of Hunter's and South's estimates, it appears likely that the other estimates refer mainly to adult slugs since trapping methods were used for sampling (see Hunter 1968).

The lowest mean density estimates recorded here were A. reticulatus 31.4×10^3 per acre, A.hortensis 15.0×10^3 per acre and A. fasciatus 1.5×10^3 per acre. The highest mean densities recorded were A. reticulatus 462.6×10^3 per acre, A. hortensis 348×10^3 per acre and A. fasciatus 163×10^3 per acre (all at Bush).

It is suggested therefore from the mean estimates made here and those of other workers and the variation in width of the fiducial intervals involved in the estimates that the ranges of 'adult' slug densities shown in Table 1 may well represent low, medium and high 'adult' populations, bearing in mind the timing of the sampling and the possibilities of quite wide fluctuation within relatively short periods of time.

These estimates refer to both undisturbed grassland habitats and cultivated arable soils. Whilst the lower estimates are probably more appropriate to the latter habitats it is suggested that a total adult slug population of 1 million per acre is not unlikely on favourable, undisturbed grassland sites.

The above estimates were calculated from samples taken at different times of the year and naturally, with regard to the controlling influence of weather and cultivations, a high adult population recorded in the spring has a different significance to a similar estimate made in the autumn, when attempting to forecast populations and possible crop damage.

Table 1.

Suggested Ranges of Adult Slug Population Densities

Species		Numbers per Acre x 10^3	Numbers per sq. ft.
a) A. reticulatus	low	2 - 50	0.5 - 1.2
	medium	50 - 200	1.2 - 4.5
	high	200 - 600	4.5 - 13.7
b) A. hortensis	low	5 - 30	0.1 - 0.9
	medium	30 - 150	0.9 - 3.5
	high	150 - 500	3.5 - 11.5
c) A. fasciatus	low	1.5 - 20	0.1 - 0.5
	medium	20 - 50	0.5 - 1.2
	high	50 - 200	1.2 - 4.5

A Comparison of Population Estimation Methods

Materials and Methods

A number of indirect methods of estimation were compared with the direct soil sampling method (described in Appendix A). Investigations were made at three sites though not all of these test methods were used at each site.

The indirect methods used were as follows:-

i) Open Pellet Groups

One uncovered group of three adjacent commercial slug pellets (hard type) placed on the bare ground or on a small 2" square of wire gauze (in both cases covered with a 4" square of wire gauze on ½" wooden legs to keep off birds and rodents), for a fixed number of days. Counts of dead and moribund slugs were made on each day. The pellets were cleared away at the end of each period.

ii) Covered Pellets

A group as in i) but covered with a biscuit tin of 6" side and measuring 9" x 8", this being pressed down 2-3" into the ground within slits made with a steel grid. The traps were inspected at daily or less frequent intervals. Where the traps were positioned over potato plants (tuber hills), the plant stems were cut off previously at ground level. In most cases, a 5" deep 'Indirect' soil sample was taken beneath the tin at the end of the trapping period to assess the trap efficiency and to determine whether or not there had been any immigration or emigration of slugs to or from the area under the tin.

iii) Tin Only

As ii) but without pellets.

iv) Cover Board

a) A measured wooden board the same size as the tins - 9" x 8" x $\frac{1}{2}$", was laid on the grass or soil surface. Those slugs visible under the boards after a known period of time were counted.

b) Cover board with pellets - as above with one group of pellets beneath.

v) Cabbage Leaf Discs

Four 1" diameter discs were spread over a 0.5 sq.ft. area, either uncovered or beneath a cover board trap. At the end of the trapping period the discs were recovered and damage assessed by placing them upon 1/10" squared graph paper and summing the eaten areas by counting the visible squares.

All traps were usually inspected at daily intervals, in the morning (9-10 a.m.), over the particular trapping period, the slugs removed and the numbers recorded at each inspection. In some cases, especially with the covered pellet traps, inspections were made at less frequent intervals, with sometimes up to 10 days between examinations.

Initial trapping tests showed that most of the above methods were applicable only to the 'adult' slug populations (slugs weighing over 25 mg) and hence that they could only be reasonably expected to give estimates of this fraction.

For a comparison of population density estimates the open pellet and cover board trap counts were treated as having originated from the same sample unit area as the direct soil sample and covered pellet trap, though slugs were obviously trapped from a wider area in many cases.

Site 1) <u>Grass Plot - Bush</u>

It was realised that those trapping methods involving the death of slugs (slug pellets) would cause some depletion of the slug population on the plots. However only a relatively small proportion of the population was killed by the controlled trapping and those slugs killed, were replaced by slugs of similar sizes, collected from the adjacent grassed areas and hedgerows.

The comparison of the five methods were made on some or all of the 16 plots over varying periods of time at intervals from January 1967 to September 1967 as follows:-

1st) January - February 1967 - Three separate three night periods - 20th January, 27th January and 3rd February.
Methods compared:- i), ii), iv)a and v).

2nd) 5th March, 1967 - One night period - i), ii), iv)a.

3rd) April, 1967 - Two one night periods -
12th April i), ii), iv)a.
27th April i), ii), iii), iv).

4th) June, 1967 - One three night period -
i), ii), iii), iv)a.

Before the traps were set out on this last occasion, eight of the plots, chosen at random, were watered with four gallons of water per plot to assess the effect of supplementary moisture on slug activity after very dry conditions had prevailed for a considerable period (3-4 weeks). The 3" and 6" deep, soil moisture tensiometers* showed readings of 40 and 30, which was very approximately equal to 10% and 13% actual soil moisture. (See constructed Pf curve, Fig.2A Appendix A.)

5th) September, 1967 - One nine night period

i) for five nights

ii) for nine nights

iv)a for five nights.

On each occasion, with the exception of period 1, the different traps were positioned (in the late afternoon) at random within selected areas of each plot such that all traps were at least 3 ft. apart. The allocation of the same trap method to the same selected area in a test period was done in order to facilitate examination and recording in the mornings at 9 a.m.

Influence of Weather Factors on Cover Board Trap Catches

Slugs observed under the 16 cover board traps on the grass plot were recorded at 9 a.m. on 22 mornings from 25th March to 22nd April, 1967. The following meteorological data was recorded at each of these inspections:-

i) Temperature at top of vegetative matter at 9 a.m. - maximum and minimum thermometer.

ii) Temperature at bottom of vegetative matter at 9 a.m. - maximum and minimum thermometer.

---

* These instruments only measure the moisture tension, which is related to soil moisture, and the actual soil moisture values had to be read from a soil moisture curve constructed from artificially prepared soil moistures with their corresponding tensiometer readings. The instruments are only capable of measuring soil moisture 'dryness' up to an upper limit of PF3 (approx. soil moisture of 5%).

iii) Temperature 1" soil depth at 9 a.m. - mercury-in-bulb thermometer

iv) Soil moisture 3" depth - soil moisture tensiometer

v) Minimum night temperature - thermograph

vi) Maximum night temperature - thermograph

vii) Maximum night humidity - hygrograph

viii) Minimum night humidity - hygrograph

ix) Grass wetness at 9 a.m. (arbitrary scale 0-3) (1) Dry, (2) damp, or (3) wet.

x) Cloud cover at 9 a.m. - Octa (1-8)

xi) Wind speed at 9 a.m. - Beaufort scale

A regression analysis of the possible influence of different weather factors on trap catch was made.

Site 2) Redskin Crop 'A' Beanston

Trial a) 16 plot, Early versus Late haulm removal Trial.

b) 36 plot, Late pellet-application Trial.

The sampling stations in each plot were chosen systematically.

The indirect methods used were:-

Open Pellet Groups (i)

Four open pellet groups (two on the ridge and two in the furrow) were set out in each plot on 9th October and the slug response over the next two nights was recorded.

Covered Pellet Traps (ii)

One covered pellet trap was set up over a plant in each plot on the 8th October. The traps were inspected on the 10th, 11th, 15th and 16th October. The trapping period was terminated at the last inspection after no further slugs had been attracted to the pellets.

Soil Sample

A 5" deep plant-soil sample was taken from beneath all 16 of the covered pellet traps on Trial a) and 12 of the traps (four replicates) on Trial b).

Site 3) Ploughed Field - Beanston

The field was marked out into 36 equally sized plots, measuring 50 yds x 50 yds in a 4 x 9 plot arrangement, in March 1968.

The indirect methods used were:-

Open Pellet Groups (i)

Four groups were set up as shown in Fig. 1, one yard away from the sampling station in each plot. Two of the groups were placed on the bare ground, one on top of a 2 x 2 inch square of wire gauze placed on the soil surface (to facilitate pellet recovery and prevent contact with damp soil) and one beneath a biscuit tin lid (8 in. x 9 in.) (to try to prevent animals and birds eating pellets, and protect pellets from heavy rain). The pellets were set out on 28th March and slug catches recorded on the three following mornings.

Covered Pellet Trap (ii)

One trap (6" deep tin) was set up in the centre of the open pellet groups on 27th March and the following examinations made:-

a) The first four traps were inspected on 2nd April (after six nights) and a 10" soil sample removed from beneath the traps. Because of the zero slug catch, the remaining 32 traps were left.

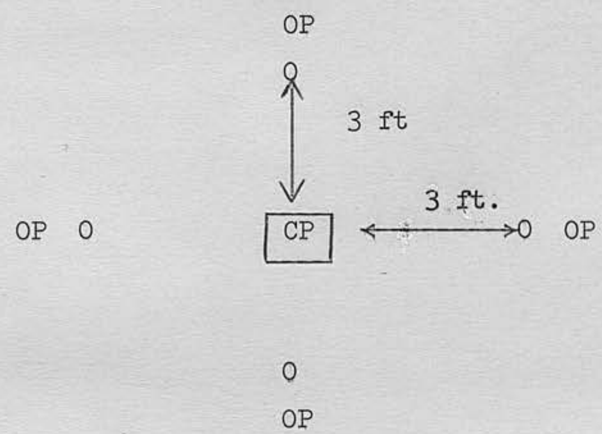
b) Traps 5-16 were examined and the soil samples dug on 5th April (after nine nights) when a slightly better catch was recorded, but the remaining 20 traps were left as the soil conditions were very wet, which made sampling very difficult.

c) On 15th April (after 19 nights) the remaining 20 traps were examined and the respective soil samples taken after a greater trap catch and when the soil was much drier.

The number of slugs in the trap catch was added to those extracted from the soil sample to give a 'control' soil sample (assuming no immigration or emigration).

Fig. 1

Diagram of Trap layout in each plot of the 20 acre ploughed field



CP - Covered pellet trap

OP - Open pellet trap

Results and Discussion

Site 1) Grass plot - Bush

For concision the results are given first in tabulated form only, as follows, and then discussed collectively.

Table 1a) Total numbers of slugs trapped by different indirect methods and soil sample counts in seven periods of comparison.

2) Correlation between the numbers of slugs trapped and soil sample counts.

3) A comparison between slug counts in the covered pellet traps and soil samples.

4) A comparison between slug density estimates from trapped and soil sample counts in two periods of comparison.

5) Numbers of slugs trapped by the open pellet groups and numbers remaining in the 0.5 sq.ft. of vegetation around the pellets after one night's trapping in April (27th).

6) Damage to cabbage discs in relation to estimated slug populations and weather.

7) Effect of supplementary watering on trap counts.

8) Effect of supplementary watering on damage to leaf discs.

9) Analysis by multiple regression of the influence of weather on cover board trap counts over 22 nights (March - April 1968).

Table 1a

Total numbers of slugs trapped by different indirect methods

and soil sample counts in 8 periods of comparison

Month	Duration of Trapping period in nights	Covered pellet-trap (ii)			Cover board (iva)			Open pellet (i)			Cover tin only (iii)			Routine sample		
		R	H	F	R	H	F	R	H	F	R	H	F	R	H	F
January	3	97	30	28	11	6	2	57	16	14				73	40	19
	3	70	27	13	66	12	18	45	14	11				73	40	19
February	3	48	16	13	70	18	17	17	1	1				73	40	19
March	1	8	6	12	17	12	5	39	14	26				83	57	27
April 1)	1	27	8	9	18	8	17	3	0	0				68	69	26
2)	1	34	28	15	34	25	27	55	41	26	20	10	10	68	69	26
June	3	62	37	35	58	11	25	57	10	14	30	8	25	38	38	16
Sept.	9	11	8	9	16	1	0	19	4	1				20	13	2

R = A. reticulatus

H = A. hortensis

F = A. fasciatus

Table 2

Correlation between the numbers of slugs trapped and soil sample counts

Month	Covered pellet Trap (ii)			Cover board trap (iva)			Open pellet trap (i)		
	R	H	F	R	H	F	R	H	F
March	0.3473	0.6881***	0.8126***	-0.2691	0.2691	.0.035	-0.062	0.078	-0.052
April 2)	0.7728***	0.4672	0.7306***	0.3643	0.0155	0.3349	0.0029	0.0496	-0.1132
Day 1	-	-	-	0.0543	-0.0941	-0.1613	0.2796	-0.2511	0.0347
June Day 2	-	-	-	-0.0279	-0.0941	-0.1613	0.2811	-0.2451	-0.0311
Day 3	0.9336***	0.7712***	0.9336***	0.3111	0.7896***	-0.2159	0.2879	-0.1927	-0.0254
	9 nights catch			1. 0.6816**	0.0000		0.2953	-0.2208	
				2. 0.7483***	0.3228	too few	0.1768	-0.2648	too few
September	0.8318***	0.4423	0.8090***	3. 0.7685***	0.2634	for	0.3499	-0.2462	for
				4. 0.7830***	0.2634	analysis	0.3831	-	analysis
				5. 0.6968**	0.1761		0.3930	-	

Table 3

Comparison between slug counts in the covered pellet trap plus indirect soil sample, and the monthly routine soil sample

Period of Investigation and slug species	Mean number per trap		Statistical significance	S.E. of Mean
	Covered pellet catch + soil sample	Routine soil sample		
March				
A. reticulatus	1.6	1.5	NS	0.087
A. hortensis	1.4	1.4	NS	0.084
A. fasciatus	1.2	1.1	NS	0.055
April				
A. reticulatus	1.6	1.5	NS	0.050
A. hortensis	1.5	1.4	NS	0.072
A. fasciatus	1.1	1.1	NS	0.063
June				
A. reticulatus	1.2	1.5	NS	0.099
A. hortensis	1.5	1.2	NS	0.086
A. fasciatus	1.2	0.9	*	0.068
September				
A. reticulatus	1.0	1.0	NS	0.090
A. hortensis	1.2	0.9	NS	0.082
A. fasciatus	0.7	0.9	NS	0.060

Table 4

A comparison between slug density estimates from trapped and soil sample counts in two periods of comparison

Month of Investigation and Sample type	Range, in number per sq. ft. and Approximate Density Range		
	A. reticulatus	A. hortensis	A. fasciatus
April			
Soil sample	4.9 - 12.1 (High)	4.2 - 11.4 (High)	1.8 - 5.0 (High)
Open pellet	4.6 - 7.0 (Medium-High)	2.4 - 7.4 (Medium-High)	1.6 - 4.8 (High)
Covered pellet	2.6 - 5.4 (Medium-High)	1.8 - 4.6 (Medium-High)	1.4 - 3.4 (High)
Cover board	3.0 - 5.8 (Medium-High)	1.6 - 4.8 (Medium-High)	2.4 - 4.4 (High)
June			
Soil sample	2.4 - 7.2 (Medium-High)	2.6 - 8.0 (Medium-High)	0 - 5.5 (Low-High)
Open pellet	4.2 - 10.6 (Medium-High)	0.4 - 2.4 (Low-Medium)	0 - 2.4 (Low-High)
Covered pellet	4.8 - 10.8 (High)	2.4 - 6.8 (Medium-High)	3.0 - 6.2 (High)
Cover board	4.0 - 8.8 (Medium-High)	0.6 - 2.6 (Low-Medium)	1.8 - 5.0 (High)

Table 5

Numbers of slugs trapped by the open pellet groups and those remaining in the 0.5 sq.ft. of vegetation around the pellets after one night's trapping in April (27th)

Species	A. reticulatus	A. hortensis	A. fasciatus
Trap Count	55	41	26
Vegetation layer	60	24	18
Total	115	65	44
Routine soil sample count	68	69	26

Table 6

Damage to Cabbage Discs in relation to estimated slug populations and weather

Month of Investigation	Length of trapping period. Discs covered or open	Total No. of Discs	Total % Leaf Area Eaten	Population Density				Minimum Night Temp. over trapping per. (°C)			State of Grass over trapping period
				No. per sq.ft.			Total				
				R	H	F					
Jan.	3-nights covered	64 - 1 missing	5.7	16.2	5.0	1.9	23.1	1.7	-0.5	-9.0	wet:wet: dry
	3-covered	64 - 3 missing	9.2	16.2	5.0	1.9	23.1	3.3	-1.0	2.8	wet:wet: wet
Feb.	3-covered	64 - 6 missing	13.2	16.2	5.0	1.9	23.1	1.7	2.8	5.6	wet: dry: cold wind
March	1-open	64 - 1 missing	25.0(3-night) (= 75.0)	10.6	8.0	3.7	22.4	3.9			damp; light rain, breeze at 6 a.m.
April	1-open	64 - 6 missing	17.9(3-night) (=53.9)	8.5	7.8	3.4	19.7	7.2			grass damp
June	3-open	64 - 5 missing	6.3	4.8	5.2	1.9	12.0	6.1	6.7	6.7	grass damp
Sept.	3-open	64 -	15.1	2.5	1.6	1.1	5.2	5.0	2.8	6.7	grass wet all 3 nights

Table 7

Effect of supplementary watering on trap counts

Trap Method	Slug Species	Mean number per trap: Wetted plots		Mean number per trap: Dry plots	S.E. of the Mean
Covered pellet (ii)	A. reticulatus	1.52	NS	1.25	0.155
	A. hortensis	1.33	NS	1.08	0.142
	A. fasciatus	1.30	NS	0.97	0.085
Open pellet (i)	A. reticulatus	1.45	NS	1.23	0.152
	A. hortensis	0.95	NS	0.81	0.073
	A. fasciatus	0.97	NS	0.85	0.073
Cover tin only (iii)	A. reticulatus	1.16	NS	0.91	0.196
	A. hortensis	0.97	NS	0.67	0.078
	A. fasciatus	1.17	NS	0.72	0.130
Cover board (iva)	A. reticulatus	1.44	NS	1.38	0.097
	A. hortensis	1.08	*	0.70	0.064
	A. fasciatus	1.15	NS	0.89	0.077

Table 8

Effect of supplementary watering on damage to leaf discs

Plot No.	Leaf area eaten (mm^2) (4 discs per plot)		
	Wetted plots	Dry plots	S.E. of Mean
1	19	11	
2	10	62	
3	7	4	
4	7	25	
5	42	39	
6	19	32	
7	22	13	
Total	126	186	
Means	2.7[illegible]	2.9[illegible]	0.81[illegible] NS

Table 9

Analysis by multiple regression of the influence of weather on cover board trap counts over 22 nights in March-April 1968

Weather Factor	A. reticulatus		Arion hortensis		Arion fasciatus	
	Regression coefficient	Standard error ±	Regression coefficient	Standard error ±	Regression coefficient	Standard error ±
1. Top grass temperature	-1.556	2.695	+1.272	1.028	+1.375	0.957
2. Bottom grass temperature	-0.128	6.289	-1.589	2.399	-3.388	2.233
3. Soil Temperature at 1"	+4.986	11.159	-1.429	4.257	+4.323	3.962
4. Night minimum temp.	+1.242	5.168	-0.730	1.971	-0.717	1.835
5. Night maximum temp.	-2.167	6.240	+2.213	2.381	+1.588	2.216
6. Humidity maximum	+1.544	1.675	+1.211	0.639	+0.704	0.595
7. Humidity minimum	-2.805	2.875	-0.749	1.097	-0.714	1.021
8. Grass wetness	+24.473	17.392	+8.964	6.634	+3.659	6.176
9. Soil moisture	-0.286	1.119	+0.046	0.427	-0.499	0.398
10. Cloud cover	-1.622	4.326	-0.108	1.650	-0.407	1.536
11. Wind speed	+1.495	1.459	+1.546	0.557	+1.214	0.518
Percentage of Catch Variance explained by above factors	54%		62%		66%	

Discussion

All of the trap methods are dependent on slug activity, which is itself greatly influenced by weather conditions, especially temperature, and slug maturity, with the exception that some activity-inhibiting weather effects such as wind are modified in the case of the covered pellet trap. The pellet traps have apparently an olfactory attraction factor which appears to differ between species and which in the case of the open pellet group operates over an unknown radius (though very probably not more than 3-4 feet in any one night - see Webley 1962). A comparison of the numbers of slugs trapped by the open pellets, those remaining in the surrounding 0.5 sq.ft. area of vegetation and the slugs from the routine soil sample in April (Table 5) showed that there had been a large immigration of A. reticulatus and A. fasciatus into the pellet trap areas, whilst those A. hortensis found near the pellets had presumably only been attracted from the immediate 0.5 sq.ft. area since there was no similar indication of higher numbers in this area

The covered pellet trap has the obvious advantage that providing there is no immigration or emigration of slugs to or from the traps then the exact area from which the trapped slugs have come is known. Hence if all the slugs under the trap are caught or a known, reasonably consistent proportion are trapped then a good estimate can be made. The comparison between numbers in the routine sample and those trapped, and remaining in the soil sample of the covered pellet traps (Table 3) showed that in all but one period (June) immigration was prevented.

A comparison of the numbers of adult slugs caught by the different methods in the separate periods (Table 1) and the correlation coefficients between the number of slugs caught by these methods and in the routine soil samples (Table 2) show that the covered pellet trap probably gave the best consistent estimate of the adult slug population of each of the three species. On some occasions the cover board trap gave a good estimate, especially of the A. reticulatus population. The negative correlations obtained between many of the trapped and soil sample estimates does not necessarily mean that the traps repelled slugs but was most probably due to the very low number involved and hence the wide error involved in the analyses.

With regard to the previous suggestions made on the approximate estimation of slug populations (page 25) it can be seen from a comparison of estimates by soil sampling and trapping in April and June that both the open and covered pellet traps gave sufficiently accurate estimates in some cases to be able to place the estimated population densities in the same category (low, medium or high) as the control soil sample estimate.

Though the % area of leaf discs eaten must be linked to some extent with the size of the slug population (Table 6), the degree of slug surface activity, controlled by weather and season had a great influence. It may also be assumed that a greater proportion of the discs are eaten by the more surface active A. reticulatus than the other two species, though in a mixed species population one could never be sure just which species were responsible for the damage.

One disadvantage of covering the leaf discs is that an exaggerated population may be responsible for the damage especially in certain weather conditions (wind) when greater aggregation appears to occur under the boards.

Some of the discs were not recovered and some were seen to have been pulled into earthworm burrows. A small amount of the edge nibbling of the discs was undoubtedly attributable to earthworms and carabid beetles by the nature of the damage.

The successful use of this method as a method of population estimation appears remote. Its original use as an indicator of feeding activity as a guide to crop damage seems more appropriate.

An analysis of the quantitative effects of different weather factors on the cover board trap counts (Table 8) show that wind speed was the greatest single controlling factor, especially in its effect on the numbers of the two Arion species. The positive correlation between an increasing wind speed and numbers of slugs caught shows agreement with the observations of Dainton (1943, 1954) in which slugs were shown to be repelled by air currents. This would account for the greater number of slugs sheltering under the boards in windy conditions.

Grass wetness appeared to have a greater influence on the numbers of A. reticulatus and A. hortensis caught than those of A. fasciatus whilst temperature probably had a greater effect on the counts of A. hortensis and A. fasciatus.

The percentage catch variance accounted for by the different weather factors for each species indicates that the behaviour of A. reticulatus may be more independent of weather than the two Arion species. This shows agreement with the field observations made here (page 153) and those of Hunter (1966a) in which relatively higher numbers of this species were frequently seen to be active on the soil surface over a wide range of weather conditions.

The application of water to the plots did not significantly increase the number of slugs trapped, with the exception of the greater number of A. hortensis counted under the cover board traps on the wetted plots, or the feeding activity, though counts on the wetted plots were consistently higher. In the case of the cover board traps, A. fasciatus showed the same trend as A. hortensis in its apparent preference for a moist refuge site whereas A. reticulatus appeared to be less exacting in this requirement.

A greater stimulation of surface activity had been expected as a marked response to the application of supplementary water to the soil surface had been obtained earlier on a 10 yard length of ridge in a potato crop. Zero surface activity was noted on a small plot of potatoes at 11 p.m. (dark) on 22nd July 1966 when soil conditions were very dry. 4 gallons of water were applied to a 4 yard length of ridge, (chosen at random) sufficient to wet the soil to a depth of 2". Within 30 minutes, 20 adult A. reticulatus and one A. fasciatus were counted on this 4 yard section whilst no slugs were seen on the rest of the plot.

Site 2) Redskin Crop 'A' Beanston

a) Haulm Removal Trial

All trap and soil sample counts are shown in Table 10.

Open Pellet Groups

Only large adult slugs were attracted to the pellet groups. The numbers of A. hortensis and A. fasciatus trapped were so few that analysis was not made. Although there was no significant difference between the numbers of A. reticulatus caught on the plots of the two treatments (Table 11), there was a significantly higher response to the pellet groups in the furrow than on the ridges. The trap estimate of A. reticulatus was too high to give even an approximate estimate (Table 12).

Covered Pellet Trap

Analysis of the numbers trapped on the treated and control plots (Table 11) showed that there were no differences in the counts of the three species on the two treatments.

The number of slugs remaining in the 5" of soil (plus tubers) beneath the covered pellet traps after the nine day trapping period are shown

Table 10

Slug Counts from traps and soil samples on all plots

of the Haulm Removal Trial

Trap - Sample and Site	A. reticulatus	A. hortensis	A. fasciatus
Open Pellet			
(2 nights catch)			
Ridge 1	5	0	0
Ridge 2	12	2	1
Furrow 1	26	2	0
Furrow 2	40	0	2
Covered Pellet			
(8 nights)	12	21	3
Residual in Soil	2	23	0
Indirect Soil Sample Total	14	44	3
Direct Soil Sample	10	32	1

Table 11

Comparison between mean slug counts on the treated and untreated plots of the Haulm Removal Trial

Sample - Slug species	Control	Treated	S.E. of the Mean	
Indirect Soil Sample				
A. reticulatus	0.90	1.11	0.07	NS
A. hortensis	1.34	1.64	0.11	NS
A. fasciatus	0.71	0.77	0.04	NS
Covered Pellet Trap				
A. reticulatus	0.42	0.39	0.04	NS
A. hortensis	0.50	0.42	0.04	NS
A. fasciatus	0.30	0.32	0.07	NS
Open Pellet Trap				
A. reticulatus				
Furrow 1	0.50	0.46	0.05 (Vertical comparison)	***
2	0.53	0.54		
Ridge 1	0.33	0.34	0.03 (Horizontal comparison)	NS
2	0.36	0.38		

Table 12

Estimates of the Population Density on the entire Haulm Removal Trial Area from trap and direct soil sample counts

	Mean number per sq.ft. with fiducial intervals at the 95% level	% Estimate of the Mean	Equivalent number per Acre ($\times 10^3$)
1. *A. reticulatus*			
Direct soil sample	1.8 ± 0.9	48	75.0 ± 37.9 (Medium -low)
Covered pellet	1.5 ± 0.7	49	65.4 ± 31.6 (Medium-low)
Open pellet (Mean of 4 pellet groups)	5.2 ± 1.4	27	226.5 ± 61.0 (Medium-high)
2. *A. hortensis*			
Direct soil sample	5.4 ± 1.8	34	234.0 ± 79.2 (High)
Covered pellet	2.8 ± 1.2	46	119.8 ± 51.9 (Medium-High)
3. *A. fasciatus*			
Direct soil sample	0.8 ± 0.5	71	32.7 ± 23.2 (Medium)
Covered pellet	0.4 ± 0.4	100	16.4 ± 18.7 (Low-Medium)

in Table 10. The traps caught 86% of the A. reticulatus, 51% of the A. hortensis and 50% of the A. fasciatus population below the tins. Correlation coefficients between the trap catch and the total numbers present were:-

0.9078 (significant at $P > 0.1$) for A. reticulatus

0.7810 (significant at $P > 0.1$) for A. hortensis and

0.6202 (significant at $P > 1.0$) for A. fasciatus,

showing that the estimates were very accurate (i.e. consistent between plots). A comparison of the population densities estimated from the covered trap catches and numbers in the indirect soil sample (Table 12) showed that the trap estimate of the slug populations was sufficiently accurate to give a good idea of the population density range. The calculated fiducial intervals showed that both for A. reticulatus and A. hortensis, the trap estimates lay within 50% of the mean.

Discussion

The open pellet groups were only useful for indicating the distribution of the species A. reticulatus on the treated and control area and showed, like the soil samples, that there was no significant difference between the number of A. reticulatus on the treated and control areas.

The numbers caught by the covered pellet traps also showed that there was no difference between the numbers of slugs of the three species on the treated and control plots. The method gave a very consistent estimate of the density of the three species, and a particularly good estimate of the number of A. reticulatus.

b) Late Pellet Application Trial

All trap and soil sample counts are shown in Table 13.

Direct Soil Sample

The plant-soil sample gave an accurate estimate (Tables 13a and 14) of the size and distribution of the population of A. hortensis on the trial area but poorer estimates of the low populations of A. reticulatus and A. fasciatus.

Open Pellet Groups

A comparison of counts of the three species on the three treatments (Tables 13, 13a) showed that there were significantly higher catches of A. reticulatus and A. hortensis on the untreated control plots. The mean estimate by the four pellet groups was reasonably accurate for the populations of A. reticulatus and A. hortensis (Table 14) though the latter was too low to place it in the same approximate density category (Medium-High) as the soil and covered pellet trap samples.

Covered Pellet Traps

Table 13 shows that on four replicates of the Trial area the traps caught 100% of the A. reticulatus, 80% of the A. fasciatus and 50% of the A. hortensis (as on the previous trial (a)). Correlation coefficients between the trap catch and total numbers present were all significant:-
A. reticulatus 0.52 (**), A. hortensis 0.79 (**) and A. fasciatus 0.94 (***).

Trap counts (Tables 13 and 13a) showed a significantly higher response on the untreated control plots by all three slug species. The estimation of population density on the entire trial area (Table 14) was quite accurate for A. hortensis (equal to the direct soil sample estimate) but much less accurate for A. reticulatus and A. fasciatus.

Table 13

Slug Counts from traps and soil samples on all treatments

of the late pellet-application Trial

Sample Type	A. reticulatus	A. hortensis	A. fasciatus
Open Pellet (3 nights catch on 36 plots)			
Ridge 1	11	8	2
2	9	5	1
Furrow 1	27	13	4
2	28	4	1
Covered Pellet- 36 plots	4	34	5
(8 nights catch 12 plots)	2	18	4
Residual in soil (12 plots)	0	17	1
Indirect soil sample total (12 units)	2	35	5
Direct Soil sample (36 units)	8	62	2

Table 13a

Comparison between mean slug counts per sample unit

on the treated and control plots of the Late Pellet Application Trial

Sample - Slug species	Control	Treatment A Earlier Application	Treatment B Later Application	S.E. of the Mean	
Direct Soil Samples					
A. reticulatus	0.06	0.08	0.06	-	
A. hortensis	1.38	1.40	1.34	0.17	NS
A. fasciatus	0.03	0.03	0.04	-	
Covered Pellet Trap					
A. reticulatus	0.34	0.29	0.29	0.02	*
A. hortensis	0.50	0.39	0.34	0.03	**
A. fasciatus	0.34	0.28	0.28	0.02	**
Open Pellet Trap					
(mean of 4 groups)					
A. reticulatus	0.45	0.31	0.30	0.02	***
A. hortensis	0.37	0.30	0.29	0.02	***
A. fasciatus	0.30	0.29	0.31	0.01	NS

Table 14

Estimates of Population Density on the Entire Late-Pellet Application Trial Area from trap and soil sample counts

Species - Sample	Mean number per sq.ft.	% Estimate of the Mean	Equivalent Number per Acre $x10^3$
A. reticulatus			
Direct Soil Sample (36 units)	0.3 ± 0.7	233	13.1 ± 30.5 (Low)
Covered Pellet (12 units)	0.2 ± 0.3	150	8.7 ± 13.1 (Low)
Open Pellet (36 units, mean of 4 groups)	1.0 ± 0.6	60	43.6 ± 26.1 (Low)
A. hortensis			
Direct Soil Sample	3.4 ± 1.3	37	152.5 ± 56.6 (Medium-High)
Covered Pellet	1.9 ± 0.7	37	82.8 ± 30.5 (Medium)
Open Pellet	0.4 ± 0.2	50	17.4 ± 8.7 (Low)
A. fasciatus			
Direct Soil Sample	0.8 ± 1.0	125	35.0 ± 43.6 (Low-Medium)
Covered Pellet	0.3 ± 0.3	100	13.1 ± 13.1 (Low)
Open Pellet	0.1 ± 0.3	300	4.4 ± 13.1 (Low)

Discussion

A comparison of the three methods on this trial site showed that the covered pellet traps gave a sufficiently good estimate of the population of the three species to be able to place them in the same Approximate Density range as that of the Direct soil sample.

The mean estimates of the four open pellet group counts were also sufficiently accurate for the species A. reticulatus and A. fasciatus, to be able to place them in the same Density range as the covered pellet trap and soil sample whilst that of A. hortensis was rather too low.

Both of the pellet traps indicated a higher surface activity on the Control than treated plots as might be expected, since a larger number of the surface active proportion of the population would have been killed by the treatment.

Site 3) Ploughed Field Beanston

Open Pellet Traps

The only species to show any measurable response to the pellet traps was A. reticulatus (Table 15). Similar numbers were caught by the two open pellet groups on the bare soil as expected, whilst the total catch of the pellet group under the tin lid over the three nights is very similar, the size of the nightly catches was different. The catch of the pellet groups on the gauze square was very much smaller than the other three, both in the nightly and final totals.

The three nightly catches of the sheltered pellets were approximately equal, whereas those of the two combined naked pellet groups showed a significant increase on each night. The lower response to the pellet groups

Table 15

Open Pellet Trap Count Totals (3 Night's Trapping)

Open Pellet Groups	Night 1	Night 2	Night 3	Total of 3 nights
1) On Bare Soil i)	24	49	62	134
ii)	35	31	56	122
2) Under Tin Lid	40	46	40	126
3) On Gauze	20	19	13	52

Table 16

Record of Weather over the Trapping Period

Trap Examination	Date	Minimum Night Temp.	General Weather Conditions	
Traps Set Out:-	27th March	2.5°C		
Insp. of Open Pellet Traps:-	28th	7.8°C	Rain	
	29th	3.3°C	Cool, soil very wet	
	30th	1.7°C		
	31st	2°C	windy, cold, some ice	
	1st April	-1°C	heavy rain, cold	
Covered Pellet Traps:-	2nd	-1°C	3" snow fall	
1-4 lifted	3rd	-1°C	heavy rain, cold	
	4th	-6°C	"	
5-16 lifted	5th	-4°C	"	
	6th	-4°C	"	
	7th	-4°C	"	
	8th	-5°C	strong drying wind	
	9th	1°C	dry	
	10th	0°C	"	
	11th	-4°C	"	
	12th	-6°C	"	higher day temps
	13th	-6°C	"	
	14th	-5°C	"	
17-36 lifted	15th	0°C	"	

Table 17

Estimates of Population Density from trap and 'control' sample counts

Sample type Species	Mean Number per sq.ft. with fiducial intervals at 95% confid. level	% Estimate of the Mean	Equivalent Number per acre x 10^3
A. reticulatus Covered Pellet Trap & Soil Sample = 'Control'	3.1 ± 0.96	32%	132.4 ± 20.9 (Medium)
Covered Pellet Trap (last 20 units)	1.8 ± 0.8	48%	78.4 ± 34.9 (Medium-Low)
Open Pellet Trap on 1) Bare soil	4.0 ± 0.7	18%	169.0 ± 30.5 (Medium)
2) Gauze	2.6 ± 0.6	23%	122.4 ± 25.3 (Medium)
3) Under Tin Lid	3.9 ± 0.7	18%	168.2 ± 29.6 (Medium)
A. hortensis			
'Control'	1.7 ± 1.3	37%	74.9 ± 27.5 (Medium)
Covered Pellet	0.6 ± 0.6	100%	26.1 ± 26.1 (Low-Medium)

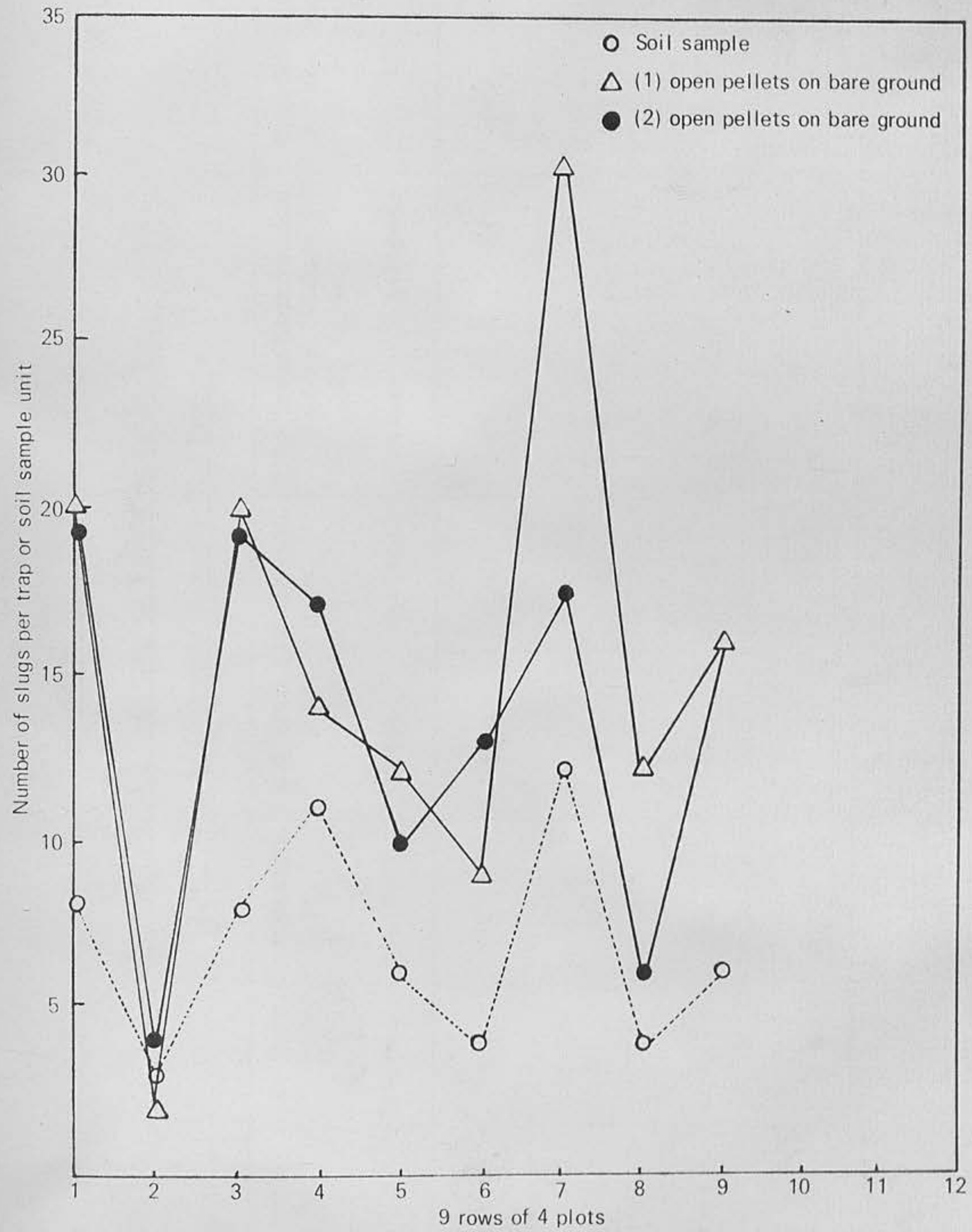


Fig 2 Counts of *A. reticulatus* from two open pellet traps on bare soil and the indirect soil sample units from the 9 rows of plots (4) on the Ploughed Stubble Field

Table 18

Covered Pellet Trap Counts Plus Counts In The

10" Deep Soil Sample Beneath The Traps

Sample Lift / Species	1st Trap Examination After 5 days (4 units)		2nd Trap Examination After 9 days (12 units)		3rd Trap Examination After 19 days (20 units)		Trap Efficiency Of the last 20 units	
	Trapped	Residual	Trapped	Residual	Trapped	Residual		
A. reticulatus	0	6	2	18	13	15	$\frac{13}{28}$	47%
A. hortensis	0	2	0	5	6	18	$\frac{6}{24}$	25%
A. fasciatus	0	0	0	1	0	2	$\frac{0}{2}$	0%

Table 19

Correlation Between Trap Counts And The 'Control' Soil Sample Count

Trap Method	A. reticulatus	A. hortensis
Covered Pellet	0.77 ***	0.38 *
Open Pellet Groups		
On 1) Bare Ground	0.49 **	-
2) Gauze	0.20 NS	-
3) Under Tin Lid	0.27 NS	-

on the gauze squares showed a slight decrease on the third night.

A record of the weather data over the trapping period (Table 16) shows that the minimum night temperature fell from 7.8°C to 3.3°C and 1.7°C over the three nights, whereas the wind force decreased, with rain showers on the first and last night.

The estimates of the adult population of A. reticulatus given by the three separate methods (Table 17), showed that all three methods gave reasonably accurate estimates of the population of A. reticulatus in comparison with the estimate by the 'control' method, with relatively narrow fiducial intervals at the 95% probability level.

Fig. 2 shows that numbers of A. reticulatus trapped by the two pellet groups on bare soil in the nine rows of four plots were positively correlated with the control sample counts.

Covered Pellet Trap plus indirect Soil Sample

The response was negligible for the first nine nights (Table 18) and a higher, measurable response was recorded on the third inspection (after 19 days). The estimates of the number of A. reticulatus and A. hortensis were fairly accurate (i.e. mean ± 32% and 37% respectively) (Table 17). The latter 20 of the 36 covered pellet traps caught 53.2% of the adult A. reticulatus and 25% of the adult A. hortensis in the trapped areas with significant correlation coefficients between trapped and 'control' sample counts (Table 19). No A. fasciatus were trapped and only nine were recovered from the soil sample.

Since only the last 20 traps gave a reasonable catch, the trapping efficiency and density estimates were based on this data (Table 17).

Discussion

The reason for the increased covered pellet trap catch with time is not clear. The minimum night temperatures tended to remain very low, though higher day temperatures were recorded over the last four days of the 20 day trapping period and this may have provided a higher part-night temperature under the traps. The soil beneath the traps remained quite damp whilst the exposed soil of the field dried out considerably over the last three days of the trial due principally to high winds. A moist soil would greatly aid surface activity. It is of course not clear just how the cover trap affected the diurnal rhythm of the slugs. By altering the light effect the slugs may have been induced to be active on the soil surface for the parts of the day-time (especially afternoon-evening) over the last part of the trial when the temperatures were higher.

The timing and duration that the pellet traps were laid down for, with regard to the weather and soil conditions, were important factors in determining the effectiveness of these methods. The two groups of open pellets on bare soil gave a consistent estimate of the number of A. reticulatus and their broad distribution on the field. The reason for the significantly lower catch by the pellets on gauze is not clear but may have been caused by an inhibition of movement to the pellet over the unnatural surface of the gauze. None of the open pellet methods proved to be of any use in estimating the numbers of A. hortensis. There are three possibilities for this:-

1) A lower surface activity of the species
2) Low attraction to the pellets (see Webley 1962 and 1964).
3) A combination of 1) and 2).

If some species are less attracted to slug pellets (which appears to be the case but which however has not been conclusively proved by controlled tests), then meta-pellets cannot be used as a relative method of estimation since a negative result in the field does not necessarily mean a lower surface activity.

The population estimate given by the covered pellet trap plus indirect soil sample (in effect a direct soil sample) was quite good, giving an estimate within 33% of the mean for adult A. reticulatus and 37% of the mean for A. hortensis. This is an improvement on the accuracy obtained in the field estimates of A. reticulatus made by other workers. The population of A. fasciatus was so low than an accurate estimate was not possible.

These estimates were taken at a time of the year when adult slug populations are fairly high, previous to the spring-summer breeding season but when total populations are not very high.

General Discussion on Methods of Estimation

These results show that the achievement of a consistently high accuracy of population estimation on a field scale with a practical number of soil sample units appears unlikely. Even in the case of estimates made on the Bush plot where 16 sample units were taken from approximately 1/19th of an acre only, the efficiency of the estimates varied widely. It appears that for practical purposes an approximate estimate of High, Medium or Low population density, with regard to the species complex, age distribution and time of year is all that is possible (or even necessary) on a cost-benefit ratio basis. The soil sampling of the 20 acre ploughed field at Beanston took approximately 8 man hours, including transportation time and the use of a tractor to remove samples from the field. The extraction of slugs from the sample took approximately another 12 man hours. However, had the field been sampled in the autumn before being ploughed, the sampling depth could have been halved (5") (higher vertical slug distribution) thus halving the number of units and probably the time taken to sample and extract the slugs.

The use of a quicker and less laborious indirect method of estimation such as, cover board, open and covered pellet traps may therefore be sufficient for an approximate estimate, especially of A. reticulatus. On many of the occasions these methods gave estimates in the same category (High, Medium or Low) as the direct soil sample. In many ways the open pellet trap is very attractive since it is very easy to set up and record though its success depends very largely on the slug species present, type of field habitat sampled and the prevailing weather during trapping.

These investigations prompted the use of 'indicator' bait pellet strips in the various potato trials and other field sites in order to assess roughly the size, surface activity and distribution of slug populations.

SECTION B

THE SPATIAL DISTRIBUTION OF SLUGS

Introduction

Part 1 To obtain further information on the spatial distributions of the three slug species an analysis of their vertical and horizontal distributions was made from the soil sampling and trapping data, collected from field and trial sites in this present investigation. It was necessary to know the type of horizontal distribution for the purpose of applying a suitable transformation to field trial data in order to make a better comparison between possible treatment effects and densities at different sites.

Part 2 Investigations were also made into the following factors which were thought possibly to have an influence on the number and distribution of slugs:- 1) Vegetative cover, 2) Soil type, 3) Cultivations and 4) Predation by some Coleoptera.

Materials and Methods Part 1

1) Vertical Distribution

The number of slugs and eggs removed from the vegetative and soil layers of the turf samples from Bush and the Grass Paddock were recorded separately. At Bush, occasional 8" deep samples were taken to keep a check on the vertical distribution over the seasons. A deeper 4" sub sample was taken at 12 of the 24 sampling stations on the compacted soil of the Grass Paddock.

Brief observations were also made on three autumn stubble fields.

2) Horizontal Distribution

(a) Grassland

Bush Data. An analysis of the total numbers of slugs recovered at the 16 sampling stations was made. Separate 'k' values (Negative Binomial series) were calculated for the distribution of adult, young and total slugs of the three species per monthly sample to assess the extent of aggregation and an overall 'common'-k-value calculated for the 19 monthly samples.

Beanston Paddock Data. The soil sample counts of the two slug species were compared with the corresponding expected distributions of the Poisson and Negative binomial series. A correlation was made between total numbers of slugs and earthworms in the sample to determine whether or not there was any relationship between the distributions of the two animals.

(b) Arable

Beanston Ploughed Field Data. The counts of *A. reticulatus* and *A. hortensis* (all of which were mature or semi-mature), from the indirect soil sample and two open pellet group catches (*A. reticulatus* only) were compared with the expected Negative binomial and Poisson distributions by the Chi squared test.

Potato Crops

Since there appeared to be no obvious difference in the numbers of slugs of the three species adjacent to the tubers of the six different potato varieties at the three trial sites (See Section D), the population distributions at the two sites, Langhill and Gateside, were analysed on the Negative binomial series, using the common values of 'k'. An analysis of the numbers of slugs in a small number of soil samples taken from the ridge (plant and interplant) and furrow of eight plots at Gateside and the sixteen plots of the Beanston "Haulm Removal Trial" was made to give some information on distribution in the ridge and furrow. Furrow samples from Beanston were taken from furrows compacted by tractor wheels and those not.

Results and Discussion

1) Vertical Distribution

Bush - Grass Plot

Initial sampling in January 1967 showed that there were no slugs below the 4" soil depth and thereafter only 4" deep samples were taken, except in July 1967, February 1968 and August, 1968, when the soil was either very dry, or very cold (frozen). There were only two slugs of each of the species A. hortensis and A. fasciatus in this deeper sample, in February 1968. Analysis of the numbers of slugs removed from the vegetative and soil layers of the routine samples (Table 20) showed:-

(i) A. reticulatus - there were always between 60%-80% of the slugs in the vegetative layer, except in December 1967 when the vegetation was frozen and in July 1968 when the great majority of slugs were newly hatched and not easily detected in the bottom of the vegetation layer before heat extraction.

(ii) A. hortensis - the proportion of slugs in the two layers varied more widely over the sampling period but in general there was a correspondingly much lower percentage in the vegetation layer each month compared with the former species. In December 1967 there were practically no slugs in the vegetative layer and again very few in July 1968 when the majority of slugs were newly hatched.

(iii) A. fasciatus - generally this species occupied an intermediate position between the two other species and showed zero slugs in the vegetative layer in December 1967, but not the low percentage (as per A. reticulatus and A. hortensis) in July 1968 when there were no young A. fasciatus present.

Table 20

Percentage number of all slugs in the vegetative and soil layers of the routine monthly turf samples from Bush

Monthly Sample	A. reticulatus		A. hortensis		A. fasciatus	
	Veg.	Soil	Veg.	Soil	Veg.	Soil
March 1967	77	23	36	64	54	46
April	70	30	30	70	65	35
May	86	14	73	27	84	16
June	74	26	19	81	47	53
July	72	28	38	62	33	67
August	73	27	44	56	50	50
September	63	37	44	56	40	60
October	83	17	55	45	76	24
November	64	36	39	61	47	53
December	17	83	2	98	0	100
January 1968	66	34	68	32	50	50
February	71	29	39	61	46	54
March	77	23	67	33	92	8
April	87	13	66	34	37	63
May	91	9	63	37	77	23
June	82	18	57	43	67	33
July	26	74	18	82	63	37

Table 21

Slug Counts in the Vegetative and Soil Layers of the turf sample from the Grass Paddock Beanston

Distribution	A. reticulatus	A. intermedius	A. fasciatus
Vegetative layer	18	54	2
Soil layer	5	17	0
% in the vegetative layer	78%	95%	100%

Table 22

Covered Pellet Trap Counts plus Slug Counts in the upper and lower 5" deep soil layers at different intervals of trapping on the Beanston Ploughed Stubble

Trapping Period	A. reticulatus			A. hortensis		
	Trapped	Top Layer	Bottom Layer	Trapped	Top Layer	Bottom Layer
5 - 8 days	4	15	8	0	4	6
21 days	15	10	1	6	9	7

Beanston - Grass Paddock

No slugs were found in the deeper sample (below 4" depth). Slug counts in the vegetative and soil layers of the 4" deep sample (Table 21) showed that there were 78% of the A. reticulatus and 95% of the A. intermedius in the vegetative layer. All of the A. reticulatus recovered except one, weighed over 25 mg. The great majority of the A. intermedius were under 25 mg (newly hatched) and it is reasonable to assume that many of those small slugs recovered by the heat treatment had remained unobserved in the bottom of the vegetative layer. The number of A. fasciatus found was so low that little could be inferred about its distribution.

Beanston - Ploughed Stubble

Slug counts in the upper and lower 5" soil layers of the soil sample taken below the covered pellet traps (Table 22) showed that 81% and 60% of the A. reticulatus and A. hortensis respectively were present in the upper layer. A comparison of the numbers of slugs in the two layers of the samples which were covered by the pellet trap for 5 - 8, and 21 days respectively showed that a higher proportion of A. reticulatus were present in the upper layer of those sample units covered for the longer period.

Autumn Cereal Stubbles

Observations on cereal stubbles in September 1967 showed that the soil on many fields below a depth of 2-3 inches was very compact and the only soil surface interstices were formed by earthworm burrows, small soil clods, stones and cereal stem-root systems. Many slugs (adult and newly hatched) and slug eggs were seen in these sites in the top 1-2" soil layer simply by pulling up the dead cereal plants and displacing stones and soil clods.

Discussion

There appeared to be a species difference in vertical distribution, and in general there was a larger percentage of A. reticulatus in the vegetative mat and upper soil layers than the other two species. The data from Bush showed that in the dry summer period, June - July 1967 there was a greater reduction in numbers of A. hortensis and A. fasciatus than A. reticulatus in the vegetation layer and again in the very cold period of December 1967 when the top 1" of soil was frozen. Thus obviously slugs of the Arionidae tend to move further down in hot, dry, and very cold weather and are generally more subterranean. Slugs of all three species were found at greater depths on cultivated than grassland and stubble soils.

2) Horizontal Distribution

(a) Grassland

Bush Data. An analysis of the Mean number of slugs of the three species and eggs recovered from the 16 sampling stations in the 19 routine samples (Table 24) showed that there was a significant ($P > 0.5$) difference in the number of A. hortensis only on the 16 plots. There was a lower population density of A. hortensis in the north corner of the plot.

The monthly values of 'k' (Fig.3) showed:-

A. reticulatus. The distribution of newly hatched young slugs (<25 mg) was more aggregated than the adult population. The degree of aggregation varied more widely for the 'adults' over the sampling period. Greater aggregation was evident in July, August, September, November, December 1967, and in March, April, June and July 1968. There was markedly less "clumping" in May 1967 and especially in May 1968.

A. hortensis. There was a higher degree of aggregation of 'adult' slugs

Table 24

Mean Total number of Eggs and Slugs per sample unit taken from the 16 grass plots at Bush in 16 Monthly samples (raw data)

Plot No.	Eggs	A. reticulatus	A.hortensis	A. fasciatus
1	1.6	1.4	1.2	0.9
2	0.8	1.5	1.2	0.9
3	0.6	1.4	1.1	0.9
4	0.6	1.3	1.1	0.9
5	0.9	1.5	1.1	0.9
6	0.9	1.4	1.1	0.9
7	1.3	1.4	1.4	1.0
8	1.1	1.5	1.4	0.9
9	1.5	1.6	1.4	1.0
10	0.9	1.6	1.4	1.0
11	1.0	1.5	1.3	0.9
12	0.6	1.6	1.3	1.1
13	0.9	1.5	1.2	1.0
14	0.4	1.5	1.2	1.0
15	1.2	1.5	1.4	1.0
16	1.1	1.6	1.4	1.1
	NS	NS	*	NS
S.E. of Mean	0.23	0.08	0.08	0.06

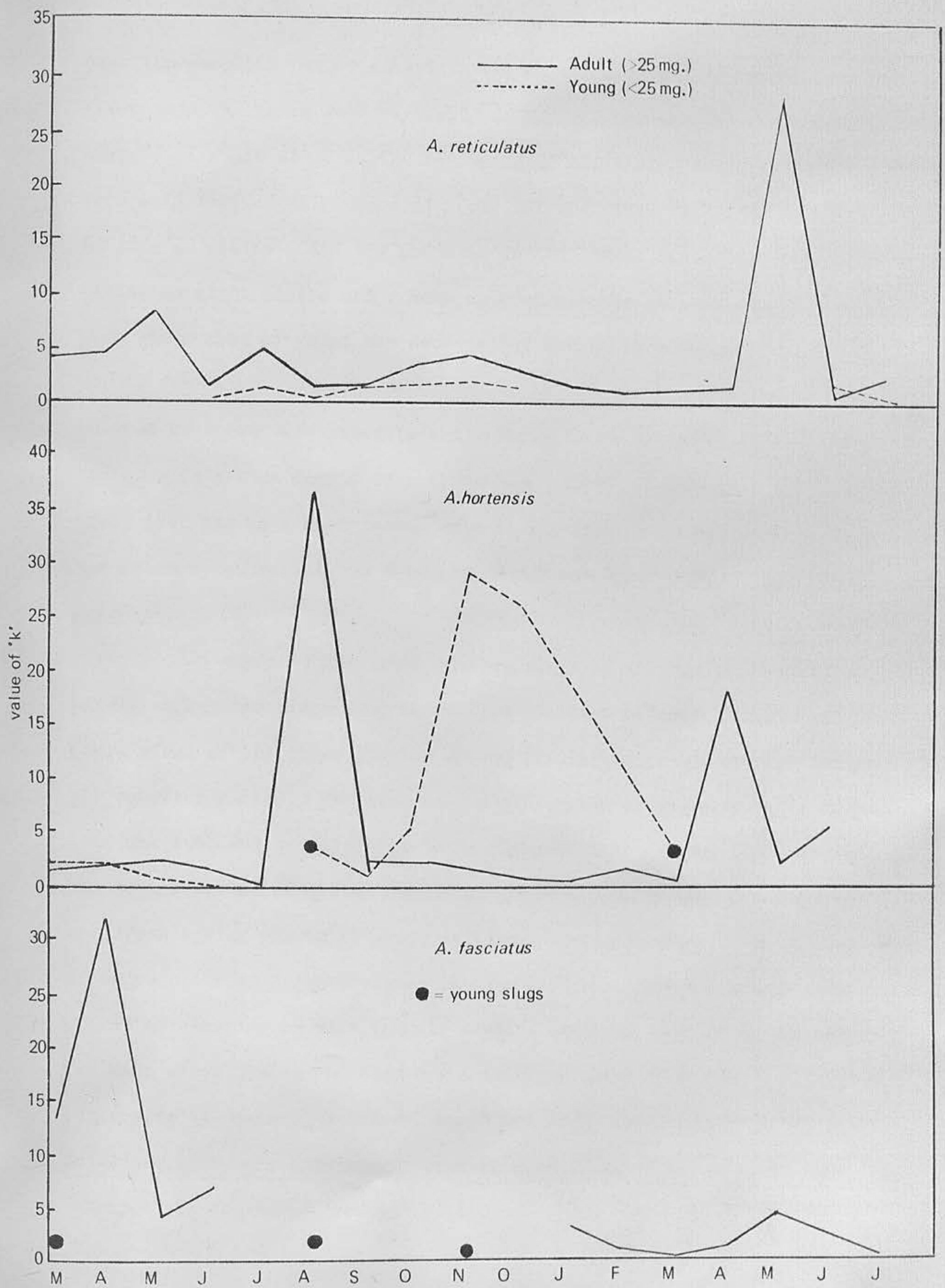


Fig 3 Monthly values of 'k' estimated from routine soil samples at Bush

over the sampling period except in (1) August 1967 and (2) April 1968 at times when (a) there were virtually no adult slugs and (b) there were greatest numbers of adult slugs at the beginning of the spring breeding season. There were only sufficient numbers of newly hatched slugs recovered in some months to give an estimate and the graph shows that there was a high degree of aggregation in eight months and a more under-dispersed distribution in November 1967 when the number of young was decreasing, due to maturation.

A. fasciatus. Only three estimates of 'k' for young slugs could be calculated as there were insufficient numbers in other months for analysis. These values show a high degree of aggregation. With the exception of March and April 1967 and to a much lesser extent, May 1968, some aggregation of 'adults' was evident, especially in February, March and April 1968.

Discussion

As expected the newly hatched slugs of all the three species were highly aggregated since they hatch from clusters of eggs. In general the adult slugs of the three species showed similar ranges of aggregation over the sampling period. The more random dispersion of A. reticulatus in May 1967 and 1968 and A. fasciatus in March-April 1967 and May 1968 may have been due to the spread of a high number of maturing adults (see Section C) within the fresh spring growth of grass in warmer spring weather. The greater amount of aggregation of A. reticulatus in June 1967 and 1968 was undoubtedly a result of clumping of this largely surface dwelling species at the relatively few damp sites during the very dry conditions prevailing then. A similar occurrence in January, February, March and April 1968 for all three species coincided with very cold frosty weather when slugs of all species were found "clumped" in sheltered 'refuge' sites.

The more random distribution of adult A. hortensis in August 1967 was probably a dispersal of rapidly maturing slugs and that in April 1968 was a similar dispersal of adult slugs in the warmer damp weather conditions when protective vegetative cover was probably of less importance as shelter. The remarkably more randomised distribution of young A. hortensis in November 1967 was very likely a result of dispersal during the short warm weather period. The significantly lower number of A. hortensis recovered in the samples from the eastern quarter of the plot may have been correlated with the generally sparser vegetative cover there and the fact that the numbers of dead leaves (providing additional moist shelter) from the sycamore tree (see Fig. 1A) were always few compared with the much greater amount on the western half of the plot.

Beanston Paddock Data. The calculated 'k' values for the two slug species were:-

A. reticulatus - 1.1082

A. intermedius - 0.6747

Both values show a high degree of aggregation. A comparison of the sample unit counts and the corresponding expected distributions both as a Poisson and Negative binomial series, with Chi squared values (Table 25), showed that the distribution of both slug species were better fitted to the former series.

A comparison was also made between the numbers of earthworms and total slugs in the sample. The correlation coefficient (+0.0371) showed that there was no close relationship between the numbers of earthworms and slugs.

Table 25

Analysis of the Slug Distribution on the Beanston Grass Paddock

Species	No. of Slugs per sample unit	Observed No. of sample units	Estimation of the numbers in the sample unit if they were distributed in accordance with either a) or b)	
			a) Negative binomial	b) Poisson
A. reticulatus	0	11	11.02	8.29
	1	6	6.16	8.81
	2	4	3.28	4.68
	3	1	1.72	1.66
	4	2	1.83	0.55
Chi squared value for 5 observations at the 5% level =		0.247	'k' = 1.108 ± 0.821 = 0.477	= 5.925
A. intermedius	0	6	6.66	0.63
	1	6	3.82	2.29
	2	3	2.72	4.18
	3	0	2.06	5.01
	4	1	1.61	4.61
	5	1	1.28	3.35
	6	2	1.03	2.03
	7	0	0.84	1.06
	8	1	0.68	0.48
	9	0	0.56	0.19
	10	2	0.46	0.07
	11	1	0.38	0.23
Chi squared value for 15 observations at the 5% level =		2.005	'k' = 0.675 ± 0.230 Chi squared = 13.015	Chi squared = 6392.27

Table 26

Analysis of the Slug Distribution on the Beanston Ploughed Field from indirect soil sample counts

Species	No. of Slugs per sample unit	Observed No. of sample units	Estimation of the numbers in each unit if they were distributed in accordance with either a) or b): a) Negative binomial	b) Poisson
A.reticulatus	0	12	11.49	7.68
	1	9	9.75	11.87
	2	5	6.41	9.17
	3	6	3.80	4.72
	4	2	2.13	1.82
	5	2	2.42	0.75
Chi squared value for 6 observations at the 5% level		= 11.070	'k' = 1.823 ±0.537 =1.743	=7.476
A.hortensis	0	14	35.41	12.88
	1	11	0.59	13.24
	2	7	0.01	6.80
	3	4	0.00	2.33
	4	0	0.00	0.75
Chi squared value for 5 observations at the 5% level		= 11.070	'k' = 28.354 ±58.176 = 541579.911	= 2.424

Table 27

Analysis of the Distribution of A. reticulatus on the Beanston Ploughed Field

1) from Open Pellet Trap Counts (2 groups on bare soil)

No. of Slugs per sample unit	Observed No. of sample units	Estimation of the number in the sample unit if they were distributed in accordance with either a) or b)	
		a) Negative binomial	b) Poisson
0	87	92.19	59.83
1	64	49.94	73.39
2	25	27.51	45.01
3	9	15.24	18.41
4	8	8.47	5.65
5	4	4.71	1.39
6	0	2.63	0.28
7	3	1.47	0.05
8	2	0.82	0.01
9	1	0.46	0.00
Chi squared value for 11 observations at the 5% level = 11.274		'k' 0.967 ± 0.192 = 15.455	= 65075.338

2) from Pellet Groups under tin lid

No. of Slugs per sample unit	Observed No. of sample units	a) Negative binomial	b) Poisson
0	30	35.35	32.24
1	47	35.85	38.37
2	18	20.85	22.84
3	6	9.12	9.06
4	2	3.33	2.69
Chi squared value for 7 observations at the 5% level = 14.067		'k' = 6.808 ± 5.542 = 14.207	= 44.804

Discussion

The results show that both slug species were aggregated within an area of 0.5 sq.ft. It might have been expected to have found a positive relationship between the numbers of slugs and earthworms since they both prefer damp, fairly densely vegetated areas, it was also thought that the earthworm burrows may have provided additional refuge sites for slugs in the relatively compacted soil on this site.

(b) Arable

Beanston Ploughed Field Data. The numbers of A. fasciatus were so few that an analysis of their distribution was impossible.

A comparison of the Chi squared values for the two types of distribution from soil sample and open pellet counts (Table 26 and 27) showed that the population distribution of A. reticulatus was overdispersed whilst that of A. hortensis was under-dispersed (not aggregated) and showed a better fit to the Poisson series.

Discussion

Though the distribution of adult A. reticulatus and A. hortensis on the field was estimated from one soil sample only, at the time of sampling (April 1968), the distribution of the former species was aggregated whilst that of the latter appeared to be more over-dispersed, on the 0.5 sq.ft.area, at least. Since A. hortensis has been shown to be frequently aggregated on grassland (see Bush data), this random distribution on ploughed land may be because of the greater number of subterranean refuge sites available and that more aggregation may occur with this species on relatively compacted grassland soils, where the number of such refuge sites are restricted.

A comparison between the species complex on the Paddock and the Ploughed Field, which was situated only 50 yards away on the opposite side of a narrow road, shows that there were no A. hortensis on the Paddock and no A. intermedius on the arable field whilst there were approximately equal numbers of A. reticulatus and probably A. fasciatus on the two sites. The aggregation of A. reticulatus was slightly greater on the Paddock. The more ubiquitous distribution of A. reticulatus is shown by the fact that this species was found on all sites sampled.

There have been conflicting views on the preferred habitat of A. hortensis. Gould (1962) suggested that this species is more abundant on undisturbed ground. Van den Bruel and Moens (1958) however, suggested that this species is usually more abundant where there is some cultivation. The observations made here tend to support the latter view though high numbers were found on the grass plot at Bush. No A. intermedius were recovered in soil samples from any other site than the Paddock but individuals were observed on numerous waste-ground sites. It appears that this species is unable to survive at all on cultivated ground though the reasons for this are not clear.

It is also interesting to note that slugs of the species M. budapestensis were only found here in gardens (on farmland) and urban areas but not in the open field. It seems likely that this species is also unable to survive field cultivations in this region because of its longer generation interval, (see Hunter, 1968a), which would tend to be even more prolonged in the colder climate of this region.

Potato Crops

The observed and expected frequency distributions of slugs recovered from the plant-soil samples at the three sites, are shown in Tables 28, 29 and 30.

The Chi squared values show that the distribution of the three species at the three sites was best fitted to the negative binomial series. The plant, interplant and furrow sample data (Tables 31 and 32) show that there was a higher percentage of total slug numbers adjacent to the tubers in the ridge at Beanston than Gateside. A. fasciatus appeared to be more numerous in the furrow than ridge at both sites though the differences were not significant. Within the ridge there were significantly higher numbers of both A. reticulatus and A. hortensis in the plant than interplant samples from Beanston whilst there were only significantly higher numbers of A. reticulatus in the plant sample from Gateside.

Discussion

The aggregated distribution of slugs of all three species showed that there was a considerable difference in the number of slugs found next to the tubers of different plants.

Though only a relatively small number of samples were taken from the interplant and furrow positions from two crops, in different localities, results suggest that at a time when slug damage to potato tubers was proceeding rapidly there was a species difference in distribution in the ridge and furrow of the crops and that there was probably no more than 50% of the total slug population next to the tubers in the ridge at any one time though those slugs of the species A. reticulatus and A. hortensis in the

Table 28

Analysis of the Slug Distribution on the Langhill Variety Trial Site from Plant-soil Samples

Species	No. of Slugs per sample unit	Observed No. of sample units	Estimation of the number in the sample unit if they were distributed in accordance with either a) or b): a) Negative binomial	b) Poisson
A. reticulatus	0	33	33.33	27.57
	1	15	19.95	20.51
	2	6	6.03	7.63
	3	1	2.63	1.89
	4	2	1.16	0.35
	5	1	0.91	0.06
Chi squared value for 6 observations at the 5% level		= 12.592	'k' = 0.940 ± 0.496 = 1.723	= 25.908
A. hortensis	0	53	53.04	48.79
	1	3	2.40	8.44
	2	1	1.00	0.73
	3	0	0.54	0.04
	4	0	0.33	0.00
	5	1	0.69	0.00
		= 12.592	'k' = 0.057 ± 0.042 = 1.164	15456.048
A. fasciatus	0	42	42.29	38.96
	1	12	10.59	15.51
	2	2	3.36	3.09
	3	1	1.14	0.41
	4	1	0.62	0.05
		= 11.070	'k' = 0.655 ± 0.321 = 0.985	= 22.934

Table 29

Analysis of the Slug Distribution on the Gateside Variety Trial Site (1st Sample) from Plant-soil Samples

Species	No. of Slugs per sample unit	Observed No. of sample units	Estimation of the number in the sample unit if they were distributed in accordance with either a) or b)	
			a) Negative Binomial	b) Poisson
A. reticulatus	0	13	12.75	10.43
	1	12	14.19	15.48
	2	14	9.69	11.48
	3	3	5.23	5.68
	4	2	2.45	2.11
	5	1	1.04	0.63
Chi squared value for 6 observations at the 95% level	= 12.592		'k' = 4.384 ± 3.699 = 3.478	= 6.793
A. hortensis	0	11	9.99	1.95
	1	7	8.23	6.11
	2	5	6.44	9.59
	3	6	4.96	10.05
	4	3	3.78	7.89
	5	4	2.87	4.96
	6	3	2.17	2.59
	7	0	1.64	1.17
	8	2	1.23	0.46
	9	1	0.93	0.16
	10	2	0.69	0.05
	= 19.675		'k' = 1.109 ± 0.372 = 6.878	=186.160
A. fasciatus	0	33	32.76	27.24
	1	6	7.37	14.28
	2	4	2.99	3.74
	3	2	1.40	0.66
	4	1	1.47	0.09
	= 11.070		'k' = 0.382 ± 0.228 = 0.999	= 17.375

Table 30

Analysis of the Slug Distribution on the Gateside Variety Trial Site (2nd Sample) from Plant-soil Samples

Species	No. of Slugs per sample unit	Observed No. of sample units	Estimation of the number in the sample unit if they were distributed in accordance with either a) or b)	
			a) Negative binomial	b) Poisson
A.reticulatus	0	14	14.32	7.70
	1	10	8.19	11.87
	2	3	4.99	9.16
	3	2	3.11	4.70
	4	4	1.96	1.82
	5	1	1.24	0.56
	6	2	2.19	0.18
Chi squared value for 7 observations at the 5% level = 14.067			'k' = 0.882 0.395 = 3.793	=32.165
A.hortensis	0	5	5.65	3.18
	1	10	8.11	7.71
	2	7	7.49	9.36
	3	4	5.66	7.58
	4	4	3.78	4.59
	5	2	2.34	2.23
	6	3	1.36	0.90
	7	1	1.61	0.44
Chi squared value for 8 observations at the 5% level = 15.507			'k' = 3.479 2.373 = 3.295	= 9.684
A.fasciatus	0	19	18.83	17.29
	1	10	10.69	12.68
	2	5	4.30	4.65
	3	2	2.18	1.38
Chi squared value for 4 observations at the 5% level = 9.488			'k' = 2.401 ± 3.114 = 0.174	= 1.041

Table 31

Slug Counts in soil samples from the ridge and furrow of 2 potato crops

Site	Sample type	A.reticulatus	A.hortensis	A.fasciatus	Total 3 species	Eggs
Beanston - Redskin Crop A	Ridge Samples					
	Plant	10	31	1	42	
	Interplant	2	4	1	7	-
	Mean	6	17.5	1	25.5	
	Furrow Samples					
	Compacted	3	18	2	23	
	Soft	4	5	3	12	-
	Mean	3.5	11.5	2.5	17.5	
	Percentage in the Ridge	63%	61%	29%	59%	-
Gateside - Variety Trial	Ridge Samples					
	Plant	19	33	8	60	63
	Interplant	0	9	2	11	11
	Mean	9.5	21	5	35.5	37
	Furrow Samples	13	24	13	50	49
	Percentage in the Ridge	42%	47%	28%	42%	43%

Table 32

Mean Number of Slugs in soil samples from the ridge and furrow of 2 Potato Crops

Site		A.reticulatus	A.hortensis	A.fasciatus	Total 3 species
1. Gateside Variety Trial	Plant	0.42	0.47	0.33	0.61
	Interplant	0.29	0.35	0.32	0.39
	Furrow	0.39	0.43	0.38	0.58
	Significance	**	NS	NS	**
	S.E. of Mean	0.023	0.036	0.018	0.044
2a) Beanston Redskin Crop A	Plant Sample	0.38	0.51	0.29	0.58
	Interplant	0.31	0.33	0.29	0.37
	Significance	*	***	NS	**
	S.E. of Mean	0.023	0.027	0.010	0.038
2b) Beanston	Furrow Samples				
	1) Compacted	0.33	0.34	0.31	0.41
	2) Loose	0.32	0.42	0.30	0.49
	Significance	NS	**	NS	*
	S.E. of Mean	0.021	0.022	0.016	0.024

ridge were definitely aggregated at the tubers.

The higher percentage of slugs in the furrow at Gateside suggests that the furrow environment there may have been more habitable than that at Beanston where considerable compaction had occurred in some furrows as a result of irrigation and machinery passage (blight spraying). The crop at Beanston was Redskin, a very susceptible variety (See Section D), whereas the sample from Gateside included both susceptible and non-susceptible varieties, and hence the slug counts in the plant soil sample from Gateside may have tended to be lower because of a lower overall attraction to the tubers (though this is not substantiated in Section D (Analysis of Slug Counts in different variety plant-soil samples). There was also a three week lapse between sampling at the two sites and it is realised that the situation may be quite dynamic, varying with time, numerous environmental and weather factors; and more samples need to be taken over the cropping period to fully ascertain the distribution patterns in the different, changing environmental niches present in potato crops. Further observations on the distribution and movement of slugs in the crop are presented in Section E with reference to tuber damage.

Analysis of Slug Count Data

In view of this confirmation of an aggregated distribution of all three slug species in very nearly all cases and because this series is in fact only a particular special case of a Poisson (i.e. random distribution), all slug count data obtained from the sampling of potato field trials was analysed as a negative binomial series. For simplicity, a common value of 'k' for each species was used in all analyses of possible treatment effects on slug numbers. These values were calculated on the computer (by the 'maximum likelihood method'), from soil sample counts at the following sites:-

1) Bush - routine turf sample
2) Langhill Variety Trial - plant-soil sample
3) Gateside Variety Trial - plant-soil sample
4) Beanston 20 acre ploughed field - soil sample

The values were computed at:-

1) A. reticulatus - 1.1049
2) A. hortensis - 1.0848
3) A. fasciatus - 0.77205

Total of the three species - 1.6350

Part 2

Some Factors Affecting Slug Numbers and Distribution

Materials and Methods

a) Vegetative Cover on a Grassland habitat

The total number of slugs of each species per sampling unit of the 19 monthly samples from Bush were compared by correlation with the fresh weight of vegetation per unit.

b) Soil Type

Ploughed Stubble - Beanston, March 1968. A very approximate estimation was made of the distribution of slugs on a 15 acre ploughed field of variable soil type in which the susceptible potato variety Redskin was to be grown. Slug pellets had been applied to a germinating crop of winter wheat three years previously and a noticeable better slug kill had been obtained on the lighter soil of 1/3rd of the field only. The field had since been cropped for two years with barley.

A continuous strip of slug pellets (one pellet every foot), 393 yards long, was put down diagonally across the field on 15th March 1968, and the dead and moribund slugs collected over measured lengths of the strip on the next morning. A visual appraisal of the soil type was made along the length of the pellet strip.

Further information on the influence of soil type on slug distribution was obtained from the slug kills by prior trapping and pellet applications on a Redskin crop at Langhill (See Section F on Control) and other field observations.

c) <u>Cultivations, Cropping and Manuring</u>

<u>Observations on crops of winter wheat and spring barley at Beanston</u>.

Following advisory reports that very little serious slug damage appears to take place on winter wheat crops grown after slug infested potato crops, an inspection was made in March 1968 on a crop of winter wheat sown after the damaged Redskin crop(A) upon which observations had been made in September-October 1967.

A simultaneous examination was also made of an adjacent crop of spring barley (sown three weeks previously). There was no dividing hedge or wall between the two crops which were thus effectively in the same field. The crop of spring barley followed a crop of oats and the stubble was ploughed in the previous November. The seed was sown (harrowed-in only) in early March immediately after the ploughing had been grubbed. The coleoptiles of the germinated barley were just visible. The winter wheat crop was sown in the previous November immediately after harvesting the potato crop. The seed bed had been considerably compacted by the winter rains and the plants were at the 3 tiller stage. In contrast the seed bed of the barley was very loose and 'cloddy'.

A 100 yard pellet strip was set up on each crop, 10 yards apart, on 15th March. The number of slugs caught were counted at 9 a.m. on the following morning.

d) Predation by Some Coleoptera

A series of short tests were carried out (at 20°C ±5°C) with adult (100-200 mg) and newly hatched (<10 mg) slugs of the species A. reticulatus, four adult Carabid species and Carabid, Staphylinid and Cantharid larvae, in ventilated plastic containers (4" x 4" x $2\frac{1}{4}$" deep) with damp filter papers. In some cases an alternative food supply consisting of two cabbage leaf discs were given per container. The tests were carried out for a varying number of days (from 1 to 37) and daily inspections made, when any devoured slugs were replaced with fresh ones. The four adult Carabid species used were, Feronia madida, F., Nebria brevicollis, F., Bembidion fluviatile, Dejea, and Trechus spp. The three Cantharid larvae used were not identified beyond the Genus. The two former species were used since large numbers were trapped on rough grassland near the laboratory and were also the only species readily trapped (by pit fall traps) on the grass plot and a small potato plot at Bush (1966). The two latter species were included as they were being used for investigations into the predation of cabbage root fly eggs (Erioischia brassicae Bouche) in the Department and were fairly common in this region on field sites. These two species were considerably smaller than the former two and newly hatched slugs only were used in tests with these two species.

Results and Discussion

a) Vegetative Cover on a Grassland habitat

A study of the correlation coefficients between Total (adult plus young) slug numbers of each species and vegetation weight in the monthly routine samples from Bush (Table 33) showed:-

A. reticulatus. There were significant positive correlations in the following months:-

1967 March, September, October,

1968 January,

and very low correlations in months:-

1967 May, November,

1968 February, March, April, May, June, July.

There were significant negative correlations in months:-

1967 July.

A. hortensis. No significant positive correlations and one significant negative correlation in March 1967.

A. fasciatus. There were no significant positive or negative correlations.

Discussion

There was no evidence of a close relationship between numbers of slugs of any of the three species and the fresh weight of vegetative cover. However, there were both significant positive and negative correlations for the species A. reticulatus. There appears to be no explanation for these significant correlations since they did not coincide with very cold or dry weather extremes, high or low slug numbers or egg hatching peaks (see Section C). It may be that the measure of fresh vegetation weight does not represent

Table 33

Correlation Coefficients between Slug Counts and the Weight of Vegetation in routine soil samples from Bush

Monthly sample \ Species	A. reticulatus	A. hortensis	A. fasciatus
March 1967	+0.963 *	-0.614 *	+0.100
April	-0.062	+0.197	-0.399
May	+0.182	+0.289	-0.462
June	+0.271	-0.0535	+0.009
July	-0.511	-	+0.421
August	-0.275	-0.190	-0.466
September	+0.514 *	-0.009	-0.047
October	+0.556 *	+0.334	-0.099
November	+0.011	+0.122	-0.914
December	-0.429	-0.292	-0.167
January 1968	+0.598 *	+0.181	+0.122
February	-0.002	+0.157	+0.149
March	+0.1801	-0.082	+0.205
April	-0.0029	+0.122	-0.191
May	+0.013	-0.117	-0.471
June	-0.059	+0.288	+0.027
July	+0.0846	+0.175	-0.286

Coefficient value significant at P>0.5 = 0.4821

Table 34

Numbers of Slugs Trapped on a Pellet-strip 'transect'

across a 15 acre Ploughed Stubble Field

	Slugs			Soil type
	A. reticulatus	A. hortensis	A. fasciatus	
1st 50 yds	36	5	0	Lighter loam
2nd 50 yds	18	2	0	" "
3rd 50 yds	10	1	1	Heavier loam
4th 50 yds	1	1	0	" "
5th 50 yds	1	1	0	" "
6th 50 yds	2	2	0	" "
7th 50 yds	5	3	0	Lighter loam
8th 43 yds	8	4	0	" "

the correct aspect of the quantitative and or qualitative degree of shelter provided by vegetative cover. It was noted during the close examination of turf units, whilst extracting slugs, that the number and distribution of slugs did not appear to be closely related to the amount or type of vegetative cover, provided there were not great differences in the moisture content of the vegetative layers. It is suggested that more refined measurements of temperature, humidity and light within small localised areas of different parts of the vegetative layer will need to be taken in order to discover the exact reasons why slugs aggregate in certain areas. It seems probable that different types of vegetation such as moss and grass will have different insulation, shading and moisture retaining properties (not correlated with weight) which may affect distribution in very cold and hot dry weather.

b) Soil Type

The results of a slug catch on the pellet-strip 'transect' across a 15 acre ploughed stubble field at Beanston (Table 34) show that the greater majority of slugs appeared to be distributed on the two lighter sandy loam sections of the field and relatively few on the heavier clay mid-section.

Discussion

Although the response to the pellet strip is only an indirect measure of the population density, one would have expected equal surface activity over the field on the one night and hence any difference in number to be reflected in the numbers trapped. The results agreed with the observations made three years previously and indicated the usefulness of pellet strips for determining the approximate distribution of a slug population on a large field scale.

In the course of investigations in this study, slugs of the species *A. reticulatus*, *A. hortensis* and *A. fasciatus* were found on soils of many types including:-

i) heavy clay

ii) heavy clay loam

iii) clay loam

iv) sandy clay loam.

On two occasions when pellet strips were used on arable sites (Gullane and Langhill Pellet trial site - Section F) a marked reduction in slug catches were recorded on the transition from sandy clay loams to areas of very sandy loam. It also appears from observations made in this study that high slug populations are not always associated with the heaviest soils as it often suggested.

c) Cultivations, Cropping and Manuring

Numbers of slugs trapped by pellet strips on two adjacent cereal crops in March 1968.

	A. reticulatus	A. hortensis	A. fasciatus
Winter Wheat	0	3	0
Spring Barley	42	3	1

The results show that A. reticulatus was caught on the spring barley only, whilst a small number of A. hortensis were trapped on each crop.

Discussion

As the species A. hortensis appears to be less attracted to pellets than A. reticulatus, and equal numbers of the former species were trapped on each crop it must be inferred that there were no A. reticulatus on the winter wheat crop.

It was noted previously, during the lifting of the potato crop that much of the ground was compacted by tractor wheelings. This, together with the subsequent cultivations prior to the sowing of the winter wheat, gradually resulting in a compacted seed bed over the winter,must have greatly reduced the largely surface dwelling population of A. reticulatus (especially the high population of young slugs and eggs present at that time) whilst the more subterranean and winter resistent species, A. hortensis, was able to survive. The much higher density of A. reticulatus in the spring barley seems surprising when it is remembered that the ploughing was cultivated (grubbed and harrowed) only three weeks before the investigation. However, the inturned surface organic layer, where the adult slugs are largely situated through the winter (Carrick 1936), would hardly be disturbed by these cultivations and the soil would not by then have compacted through continuous rain, and hence the more robust adult slugs would have easily survived.

The much tougher skin of the Arion species must also be a distinct advantage for surviving cultivations and is possibly an evolutionary adaptation of this Genera consistent with their more subterranean existence. Other observations made here and by other workers on the feeding habits and low surface activity of this Genera suggest that a less proteinaceous diet of organic matter (including quite large amounts of soil) and lower feeding activity (probably correlated with a lower metabolic rate and slower growth rate) is a further aid to survival in a more subterranean environment. It appears from previous work and observations made here that there are two separate mechanisms for ensuring the species survival of the species A. reticulatus and A. hortensis. Although A. reticulatus is much more susceptible to mortality factors, including frost, drought, cultivations, scarcity of food etc., it has a very high capacity for increase (see Laughlin, 1965) which enables it to quickly exploit a suitable environment under favourable weather conditions. A. hortensis, has on the other hand a much lower capacity for increase, principally because of its larger generation interval (Section C) and thus depends more on the survival of the individual for the continued existence of the species.

It would seem obvious that slugs would multiply more rapidly in situations where the habitat is relatively undisturbed. Thus in general with the rotation used in this region, slug populations are likely to be suppressed by the autumn seed bed preparations for the winter wheat crop following potatoes, but the populations are likely to increase over the subsequent 2-3 years of barley crops. This is because usually, the only autumn cultivation following the cereal harvest is the ploughing-in of stubble and F.Y.M., which places the slugs in the surface layers at a deeper level along with surface organic matter serving as a food source, and they are probably protected from winter frosts and desiccating winds. Cultivations in the following spring usually involve the preparation of the top 4" or so of soil for a seed bed, and unless a very compact bed is obtained, the slugs, left undisturbed in the interned organic-straw layer, can resume surface activity in the warmer late spring months. During the summer months of cereal cropping the environment is left relatively undisturbed, which is highly suitable for slug activity and breeding. Likewise, other dense ground cover such as peas are conducive to unimpeded slug activity over the summer months. Conversely, the traditional frequent inter-row cultivations carried out in row crops such as turnips, sugar beet etc., creates a disturbed environment with less vegetative ground cover which is a greater impediment to population increase, especially in dry conditions. It would be interesting to know to what extent the increased use of chemical weed control, in place of soil cultivation, is affecting slug populations. Population build-up is probably the highest on grass crops providing the soil has not been too compressed initially in the seed bed preparation.

The practice of applying large quantities of F.Y.M. to stubble prior to winter ploughing greatly aids the survival of the interned slugs (Carrick 1936) and the author has noted the collection of slugs of all the three species in this usually frost-free pocket of interned organic matter during the winter and early spring months. Batches of eggs laid in early spring have also been found by the author in these organic layers (Ploughed Stubble - Beanston March 1967) where breeding can probably commence somewhat earlier than under more exposed surface situations.

d) Predation by some species of Coleoptera

The results of the tests, given in Table 35, show that only the adult *F. madida* were capable of attacking and successfully devouring adult *A. reticulatus*, even in the presence of an alternative food supply (which was seen to be readily eaten in prior observations), whereas *N. brevicollis* appeared unable to successfully attack and eat large slugs. It was observed that the excessive mucous secretions emitted by the attacked slugs caused considerable impediment to the feeding *F. madida* which were obliged to continually clear away the mucous from the mandibles by rubbing them on the filter paper.

All four Carabid species were able to attack and eat the newly hatched slugs, and considerable numbers were eaten by *F. madida*. Two slug eggs (*A. reticulatus*) were also attacked and burst open by the Staphylinid larvae.

Discussion

Though the test conditions were very artificial and may bear little

Table 35

Numbers of A. reticulatus eaten by some species of Coleoptera

Species of Coleoptera and number per Test		Time Period of Test (Days)	Adult Slugs Eaten	Newly-hatched slugs eaten
Adults				
Feronia madida	(2)	32	17	-
" "	(1)	12	3	-
" "	(1)	15	1	-
" "	(2)	25	0	-
" "	(1)	13	7	-
" "	(2)	26	3	-
"+ cabbage leaf disc	(2)	17	-	22
	(1)	9	-	16
"+ cabbage leaf disc	(1)	21	4	-
Nebria brevicollis	(1)	7	0	1
" "	(2)	37	0	-
"+ cabbage leaf disc	(1)	-	-	9
Bembidion fluviatile	(2)	11	-	2
	(1)	9	-	3
	(2)	20	-	3
Trechus spp	(6)	11	-	2
	(2)	1	-	2
Larvae				
Staphylinidae	(1)	4	2	2
Carabidae	(1)	13	-	15
Cantharidae	(1)	13	-	3
Cantharidae	(4)	8	-	11

relationship to natural conditions, it was shown that the common Carabid species F. madida was capable of killing and eating adult slugs and large numbers of newly-hatched slugs. It is interesting to note that even the very small Trechus spp were also able to eat the newly-hatched slugs.

It is suggested from these tests and those of other workers (notably Stephenson, 1964) that a number of these very active and voracious Carabid species (including numerous larger species not tested here but found in many localities e.g. Feronia nigra, F., Feronia vulgaris, F., Carabus violaceus, L.) may exert a significant contolling effect on slug populations, principally, it is suggested by eating the very small, newly-hatched slugs which are devoured more readily. Though the numbers of predatory beetles may not be high, on arable sites especially, they are very active and appear to forage over relatively large areas (cp Successful use of pitfall traps). Numerous slugs collected in the course of this study were seen to have wounds which were comparable to those caused by the mandibles of the larger Carabid beetles in the laboratory tests.

There may be a similar parallel situation to the natural control of the cabbage root fly by Carabid beetles whereby the recent more extensive use of non-specific pesticides may be killing off the Carabid predators of slugs and hence aiding an increase in slug numbers.

SECTION C

SEASONAL POPULATION FLUCTUATIONS AND LIFE CYCLE STUDIES OF THE SLUG PEST SPECIES

Introduction

It appeared from the literature that the life cycles of the three slug species being investigated may vary considerably under different climatic conditions. As there have been no detailed investigations in this region, based on a reliable soil sampling method, it was decided to try and obtain such information from routine soil samples. Further, there is no recorded information on the life cycle of the species A. fasciatus other than occasional observations made by Barnes and Weil (1944) and Carrick (1936).

Materials and Methods

Slugs recovered from the monthly routine turf samples at Bush were weighed individually and frequency tables were compiled as per Hunter 1966 and Bett 1960. Slightly different categories were used, however, as follows:-

1) Newly hatched slugs weighing 0-10 milligrams (designated the abbreviation 'ry', 'hy' and 'fy' for the species A. reticulatus, A. hortensis and A. fasciatus respectively).

2) Very young slugs, probably less than six weeks old, weighing 10-25 milligrams (r, h and f).

3) Medium-small sized slugs measuring approximately 1 cm and probably less than two months old, weighing 25-75 milligrams (rm, hm, fm).

4) Medium-large slugs approximately 1-5 cm long and between two and six months old, weighing 75-150 milligrams (Rm, Hm, Fm).

5) Large adult mature slugs approximately six to twelve months old, weighing over 150 milligrams (R, H and F).

The sample recovery methods used (see Appendix A) allowed the recovery of eggs from the vegetative layer and top inch of soil sample and this data was used in the compilation of representative life cycle data for each species.

Results and Discussion

Although the method used in assessing maturity was only approximate it showed the main hatching, growth and senescent periods of the broad generations. It was apparent that the greatest weights attained by mature slugs of the three species on the grass plot were quite low (200-300 mg) in comparison with those (300-500 mg) recorded by other workers and observed and collected in soil samples from potato crops and other field sites in these investigations. It is suggested that this was due to an attenuation of growth because of low temperatures prevailing at the relatively high altitude of Bush and to the lower proteinaceous diet afforded by the coarse grass species on the plots.

1. A. reticulatus

Total numbers (Fig. 4)

The greatest numbers of slugs occurred in March and December 1967 and February and July 1968 and the lowest in June, September and November 1967 and January and June 1968.

Newly hatched slugs (Fig. 5)

Numbers increased steadily from June. There was a small hatch in March-April and zero hatches in May and June 1967, but reaching a peak in August. A gradual decrease followed, and numbers were low by October and November. There was then a sharp increase in December. During the winter

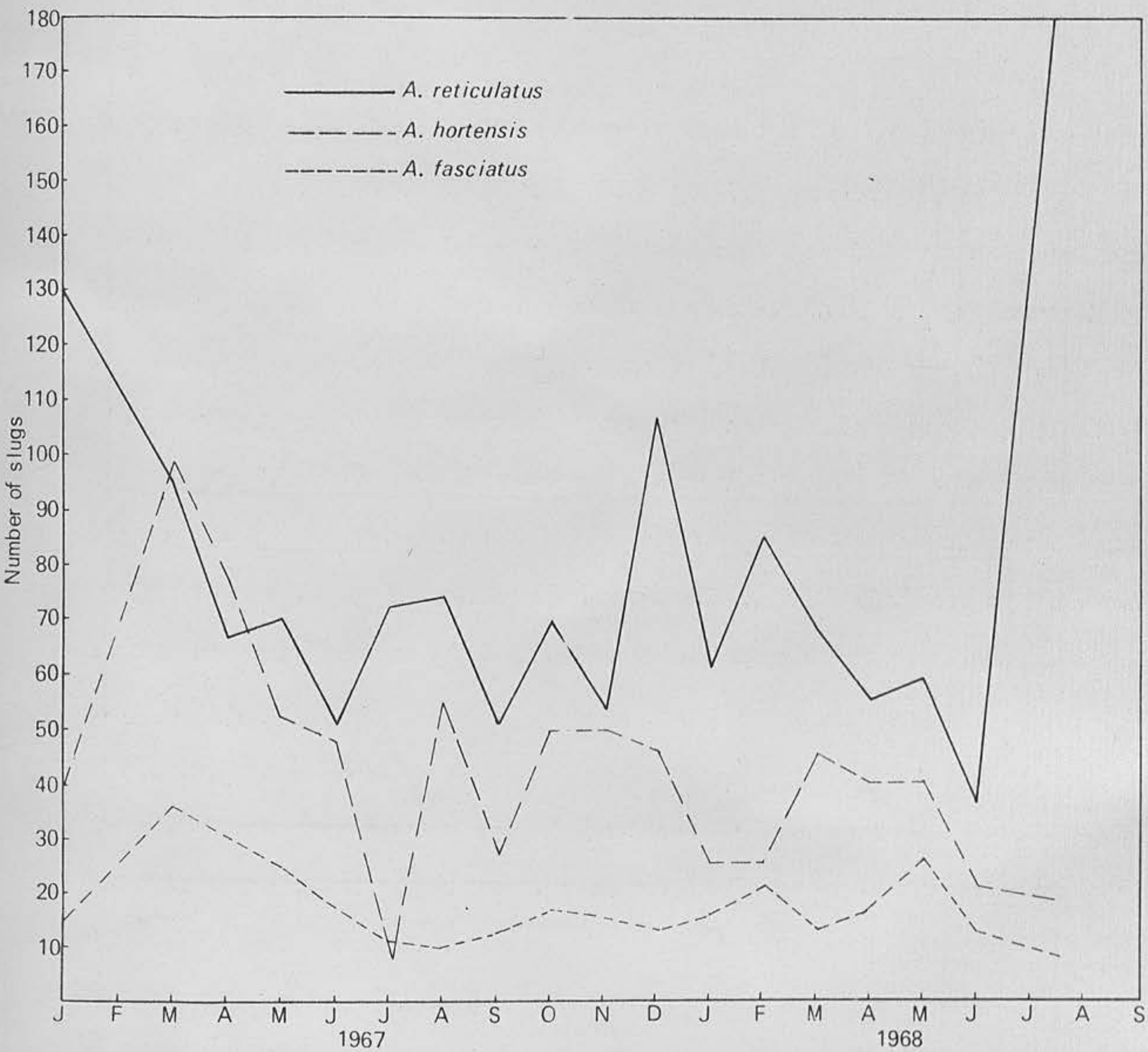


Fig 4 Total numbers of slugs in the routine monthly soil samples from Bush

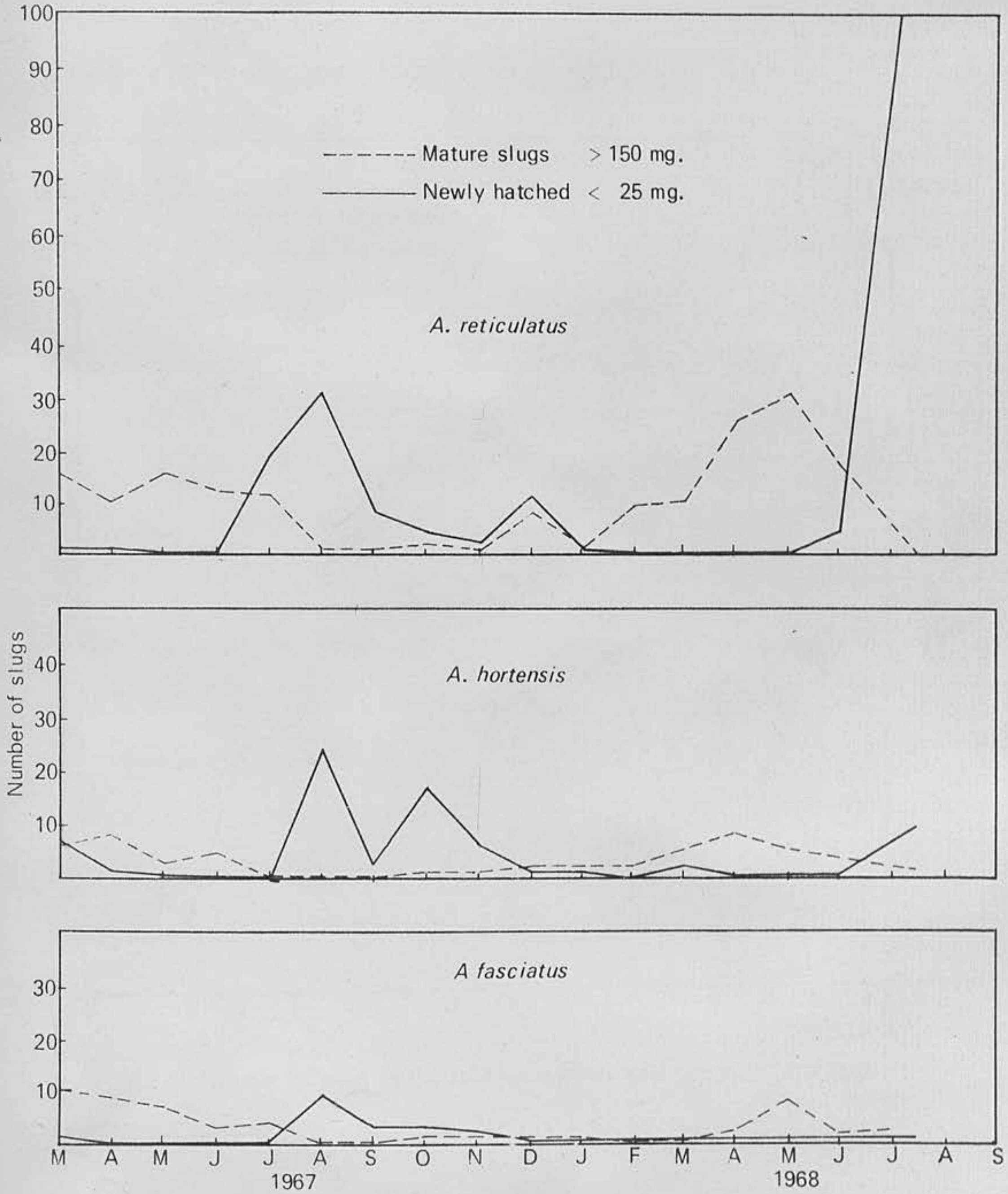


Fig 5 Numbers of mature and newly hatched slugs in the routine monthly soil samples from Bush

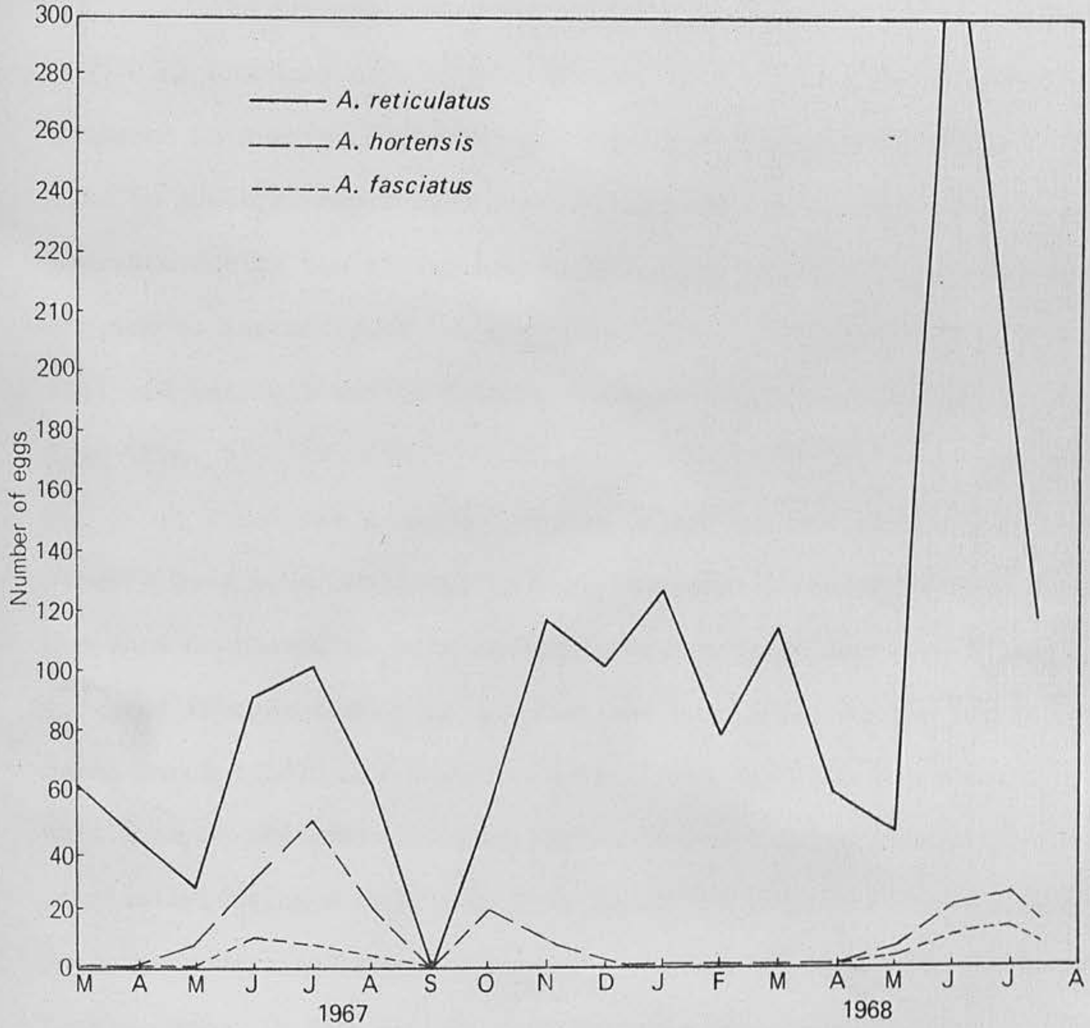


Fig 6 Number of eggs in the routine monthly soil samples from Bush

and early spring months of 1968 (January, February-March, April and early May) hatching was negligible, but recommenced in June. In July there was a very large hatch of the high numbers of eggs laid between mid-May and mid-June.

Mature slugs (Fig. 5)

The highest numbers of mature slugs occurred in the March, April, May, June and July of 1967 with a peak in May. After July, a rapid decline followed to August, September and October. In November there was a rapid rise in numbers, reaching a peak in December. This was followed by a steady increase during the winter and early spring months of 1968, increasing from January to another peak in May. This latter peak was similar to that of May 1967 and was followed by a sharp decrease in numbers during June and July.

Eggs (Fig. 6)

There was a rapid decrease in egg numbers from a high level in January 1967 to a low level in May. Numbers increased between May and July and then decreased to zero in September. A rapid increase in egg laying occurred from September to November and then numbers were fairly constant until March 1968. Low numbers in April and May 1968 indicated a hatch during this time, of the overwintering eggs. In June, oviposition increased substantially, being much higher than in any of the preceding months and this presumably resulted from either a much larger adult population in May 1968 than occurred in May 1967 or more suitable conditions for oviposition in June 1968.

Discussion

The life cycle of A. reticulatus appears to differ, to some extent, from that described by Hunter(1968a).The main periods of hatching occurred from the end of July to the end of September and from mid-October to the end of January with peaks in August and December as compared to the more distinct spring and autumn peaks in May and September described by Hunter and South (1965). It appears that because of the colder weather in spring and early summer prevailing at the relatively high altitude and more northerly latitude of the Bush Estate, the start of the spring oviposition and hatching periods, - in March and May respectively, as described by Hunter, Bett (1960) and South (1965) - occur later, in June-July, and August-September, and the autumn oviposition and hatching period also takes place later than the August to November period, as described by Hunter. The autumn period of egg laying commenced in October and reached a peak in November, whilst hatching increased steadily from low initial numbers in October to a small peak in December.

Carrick (1938) suggested that the period of greatest reproductive activity in South East Scotland occurred between late August and November and that eggs and young slugs are most abundant during this period, because the weather was too dry and warm for slug activity before August. However, although dry periods did occur in June and July in 1967 and in 1968, this did not prevent oviposition here, for the summer oviposition peaks occurred in these two months in both years. There was general agreement with Carrick's observations in that large numbers of young slugs were present during this period, as well as earlier in July and again later in December. These differences may be simply a reflection of different yearly weather conditions.

The low numbers of eggs found in May 1967 and May 1968 corresponded with the highest number of mature slugs recorded, in both years. The subsequent sharp rise of oviposition in June 1967 and June 1968 followed by the increasing hatch of these eggs during July and August was accompanied by a rapid fall in the numbers of mature slugs, indicating that this spring-summer adult population died off shortly after ovipositing. This confirmed the findings of Hunter; and although he did not record any general trend in egg numbers, the present work shows a definite peak in June-July and during the winter months. The high egg peak in July 1968 shows agreement with the findings of South and Bett who recorded a higher egg peak in spring than in autumn. This supports the suggestion that the population level varies from year to year as a direct result of weather influences on maturation, mortality, oviposition and hatching.

The absence of eggs in mid-September 1967 was due to the almost complete absence of mature slugs on the plot at that time, and oviposition did not commence until numbers of adults increased in late September, October and November. This increase in adult slugs from late October to December was due to the maturing of the spring and early summer generation which hatched between March and July 1967 from the eggs laid in the late autumn-winter period of 1966 and the early spring of 1967. Those slugs hatching after July and up to December 1967 matured more slowly during the winter months, to give the recorded peak of mature slugs in May 1968. Eggs laid in the late autumn and early winter, which resulted in the peaks in January and March, would not have hatched until the following spring (between March and June), just prior to the hatch of the eggs laid between late May and early June, at the start of the spring and summer oviposition period.

Thus, although egg laying and hatching apparently occurs to some extent in all months and slugs at almost all stages of maturity were found in each month, there would appear to be two main generations per year. The formation of these two broad generations results from the restrictions placed on the otherwise continuous breeding cycle by the cold conditions of winter and early spring during which period hatching is negligible. It would be interesting to see whether or not continuous breeding takes place throughout the year in warmer southern climates, though very dry periods would probably also limit breeding, oviposition, and hatching.

Although the present studies were of limited duration it appears that in the South East of Scotland two main generations of A. reticulatus can be distinguished:- a) slugs hatching in spring and early summer. These grow quickly during the warm summer and early autumn months to mature in the late autumn and early winter months when the majority of them oviposit. b) Slugs hatching in the late summer, autumn and early winter months. These grow more slowly during the cold late autumn, winter, and early spring months, to mature at a greater age in the late spring and early summer.

A. reticulatus is very fecund and is able to grow and mature rapidly in favourable weather and it appears that weather conditions are the major controlling factors for individual and population growth. Small variations, therefore, in the timing of maturation, oviposition and hatching are evidence of varying yearly and seasonal weather conditions.

2. A. hortensis

Total numbers (Fig. 4)

There was a rapid decrease in numbers from March 1967 to July 1967, which was followed by a sharp rise in August. A further rise in September preceded a numerical peak in October, November and December 1967. Fewer slugs were found in January and February 1968 but then numbers rose to a peak in May, and declined again to August.

Newly hatched slugs (Fig. 5)

The main hatching periods were between mid-July and the end of August, and between the end of September and the end of November in 1967, and again in the period July-August 1968. Very small hatches took place during the winter, and only small peaks occurred in March and May 1967, and in March 1968.

Mature slugs (Fig. 5)

The number of mature slugs declined from March 1967 to a very low level by August. Very few mature slugs were found during the months August to October 1967, but thereafter numbers rose gradually throughout the winter of 1967 and the spring of 1968 to reach another small peak in April 1968. Numbers subsequently decreased gradually to July and August 1968.

Eggs (Fig. 6)

In 1967 eggs were recovered in June, July and August with a peak recovery in July, while in 1968 the peak recovery period was in June.

Discussion

The results indicate that the main hatching period occurred between July and November with a very small hatch during the winter months, and a small peak in early spring. The start of the summer hatch in July appears to be up to a month later than that recorded by Hunter.

Bett (1960) confirmed the findings of Barnes and Weil (1944) that slugs of this species are most abundant in October and November and least abundant in June and July, and the present work shows some agreement with this. Bett inferred from her sampling data that most of the hatching takes place in

January and February but the present observations do not confirm this and it is very likely that Bett may have missed some of the very young slugs in the summer months by using the night searching method (cp Hunter 1968a). Stephenson (1967) also states that the main hatch takes place in November to February in South East England but recognises that the cycle may vary in the North of England. However, Bett's work does not agree with that of Stephenson (both recorded at Rothamsted, Hertfordshire), for her records (1957) show that the maximum numbers of mature mated slugs occurred from February to April and that these had died off by June; though the eggs subsequently laid by June and July would surely have hatched before November.

The present records confirm the rapid decrease in numbers of mature adults in July after reaching a peak in April, as described by Bett and Hunter. However, as a rapid increase in newly hatched slugs occurred here in August (recorded in late June and August by Hunter) it is suggested that the bulk of the mature, overwintering slug population dies off soon after ovipositing in May, June and July. It appears that in South East Scotland the majority of slugs have an annual life cycle, hatching between July and November, growing during the winter and spring months and maturing in the following April, May and June, when they copulate, oviposit and then die shortly afterwards. It seems probable that slugs hatching during the winter and early spring may not mature until the spring of the following year and so in some cases individuals may take eighteen months to mature.

3. A. fasciatus

Total numbers (Fig. 4)

Compared with A. hortensis and A. reticulatus the numbers of

A. fasciatus present throughout the year were significantly fewer and density fluctuations far less. The highest numbers were recorded in March 1967. They then decreased until April and increased again in May. There was a gradual decrease in numbers to August and September followed by a gradual but fluctuating increase during the winter and spring, reaching a peak in May 1968. Numbers decreased again after May as they had done in May 1967, to a low level in July-August.

Newly hatched - juveniles (Fig. 5).

Although there was a small hatch in March 1967, the main period of hatching took place between the end of July and November. There was a further small hatch in January 1968 followed by zero hatches in February, March, April, May, June and July. Trapping records also showed a considerable hatch in late August 1968, as in 1967.

Mature slugs (Fig. 5)

Numbers of mature slugs decreased up to August 1967,and from then until March 1968 very few were recorded. In April-May 1968 there was a small increase in numbers, followed by a decline, as in 1967.

Eggs (Fig. 6)

Only small numbers of eggs were recorded in the June, July and August periods of 1967 and 1968.

Discussion

Although the population of A. fasciatus on the area studied was small compared with that of A. reticulatus and to a lesser extent that of A. hortensis, sufficient data was obtained to give a reasonably clear indication of the life-cycle.

Little previous work has been done on the life-cycle of this species. Barnes and Weil observed that A. fasciatus reached their largest size during the winter months and suggested that they may prove to be more active between October and May than during the rest of the year. Carrick (1936) recorded the presence of both adult and young slugs in potato fields in late autumn. The present work shows some agreement with the observations of Barnes and Weil, since the largest slugs were recovered in the spring of both 1967 and 1968, although the period of greatest surface activity was observed in early July 1968. The records here also agree with those of Carrick in that newly hatched and semi-mature slugs were present in the late autumn.

A small number of slugs weighing between 25 and 75 mg were collected in May 1967 and kept in an open insecty culture. They grew slowly during the summer and winter and matured in June 1968. Eggs were laid by slugs ranging in weight from 164 mg - 350 mg in early July and these began to hatch in early August.

From the monthly soil sample and culture data it appears that the majority of A. fasciatus have an annual life cycle. They hatch between July and November and grow slowly during the winter and early spring months to mature in the late spring and early summer. Oviposition then takes place. The culture data shows that slugs of a fairly wide weight range reach maturity at approximately the same time and this suggests that slugs hatching as far apart as August and October could reach maturity during the same periods in spring and early summer. Obviously the slugs hatching in early spring will reach a greater size and weight by the following spring than those slugs hatching during the summer and autumn months.

SECTION D

SUSCEPTIBILITY OF DIFFERENT POTATO VARIETIES

Part 1 - Field Investigations

Introduction

As a result of a pilot test carried out in 1966 the main crop varieties, Redskin (R), Kerr's Pink (KP), King Edward (KE), Golden Wonder (GW), Majestic (M) and Pentland Dell (PD) were chosen for closer study. The test showed these varieties to cover the suspected range of susceptibility to slug damage. The acreage of Pentland Dell is small as it is a comparatively new variety. Until the last season, when this variety appears to have fallen from favour because of its susceptibility to 'little potato' disease*, it was thought that it would become very widely grown because of its very high yields and resistance to blight. The variety Pentland Falcon, reported to be slug resistant (Gould 1965) was also to be included. It appeared, however, that it would not be widely grown in the future because of its susceptibility to internal rust spot and was not therefore included as a commercial possibility. The varieties Redskin, K.Pink and G. Wonder, are generally grown more for home consumption whereas K. Edward and Majestic are grown more for the English seed trade.

Trials were carried out in 1967 at three sites known to support reasonably high populations of the three species of slugs under study and which had records of slug damage to crops in previous years. These were at Beanston (East Lothian), Langhill (Midlothian) and Gateside (West Lothian). The weather, as well as the soil type, differed at the three sites. West Lothian had a very

---

* a physiological defect whereby tuber setts planted at low soil temperatures fail to develop properly.

wet summer whilst East and Midlothian were much drier, the latter being the wetter of these two.

Materials and Methods

Two trials (Beanston and Gateside) consisted of eight replicates, and one trial (Langhill) of ten replicates, of the six varieties in randomised blocks of six. The plot size for each variety was five drills wide and eight setts long, giving a square plot 12 ft. x 12 ft. Unfortunately, the blocks had to be arranged in the form of an oblong instead of the desired square, to avoid causing undue inconvenience to the farmers on whose land the trials were carried out. The outer row and two end plants of each plot formed the guard area, leaving three rows of six plants for subsequent examination. The size of each block was 23ft. x 36 ft. and the trial area 23ft. x 228 ft. (10 replicates). The trials were planted out on the following dates:-

Beanston	-	19th April
Langhill	-	10th April
Gateside	-	24th April.

F.Y.M. was applied to the three trial areas at the rate of about 15 tons per acre during the winter and a dressing of potato fertiliser (N:P:K:- 10:10:10) was applied at the rate of 7.5 cwts per acre, prior to planting. The tuber setts were covered by machine after planting and thereafter ridged only once, in June, when the plants were between 6" and 1' high. No further cultivations were made and blight sprays were given as required by the farmer. No weed control measures were taken except prior to harvesting.

On the first two trial sites observations were made shortly after planting to try and estimate the slug population on different parts of the trial area. Cover board traps measuring 12 inches square, with and without a halved potato (as bait) beneath, were laid down in the furrows and examined in the early morning at intervals over one month. The numbers recorded were so low however that analysis of the results was impossible and they were disregarded. In July and August a small number of plant samples were examined to assess the size of tubers and rate of tuber formation, and to record any initiation of slug damage. Observations were also made on the state of the haulms throughout the growing season and their susceptibility to disease attack. At Beanston and Gateside the haulms were killed off with 'Reglone' on the 22nd and 26th September respectively because of blight infection and excessive weed growth.

Prior to the lifting of the tubers in the trials, 5" deep plant-soil samples were taken from the three sites as follows:-

1) <u>Beanston</u> - 17th October, 1967 - one plant-soil sample from each plot of four random blocks of the trial.

2) <u>Langhill</u> - 25th, 26th October, 1967 - one plant sample taken from each of the sixty plots.

3) <u>Langhill</u> - 3rd November, 1967 - from two blocks, additional 'inter-plant' ridge samples and furrow samples were taken.

4) <u>Gateside</u> - 1st November, 1967 - plant samples taken from the eight blocks together with 'inter-plant' and furrow samples from three of the eight blocks.

5) <u>Gateside</u> - 7th November, 1967 - immediately prior to lifting the trial, a second plant-soil sample was taken from each plot of seven blocks (the eighth block being waterlogged).

The tubers from these samples were washed and examined for damage, whilst the slugs were recovered by the progressive flooding of the soil in large cans.

In some cases the recovered slugs were housed individually in petri dishes and their faeces examined for potato tuber starch using iodine solution.

Field inspections of the tubers (lifted by hand) were made at Beanston on 18th October when soil conditions were dry. Each tuber (>1" diameter) of the eighteen plants per plot was inspected and recorded for damage. Tubers of each plant were inspected separately to give individual plant damage assessments. Because of muddy conditions, only four blocks could be examined in the field at Langhill (1st November) and none at Gateside (8th November). Instead, the tubers were lifted, bagged, and subsequently washed on a potato washing plant at the East Craigs Plant Diseases Research Centre and examined. This meant that information on damage to individual plants was not available for Gateside nor for the most of the Langhill trial.

The washed tubers were divided into ware and seed size using 2.25" and 1.25" sieves, and separate examinations were made. A class for 'rejected tubers' was made, whereby very badly damaged tubers were rejected as being unfit for normal commercial use. This was an arbitrary classification and generally included tubers with three or more penetrating slug holes, or a large cavity. Tubers were also weighed to give estimates of the weight of damaged and rejected tubers as a fraction of the crop.

The following measurements were made in the field and washed tuber examinations:-

i) percentage of plants with damaged tubers,

ii) percentage of tubers damaged,

iii) total number of slug holes per variety,

iv) the number of holes per damaged tuber,

v) percentage weight of damaged tubers per total tuber weight) washed
)
vi) percentage weight of rejected tubers per total tubers) tubers only

Results and Discussion

Plant Growth

With the exception of the variety P. Dell at Langhill, which only showed 50% emergence because of 'little potato' disease, there were only slight differences in plant growth at the three sites. K.Edward and Majestic grew rather more quickly than the other varieties and tuber bulking commenced earlier, the tubers of the former being formed at a rather more shallow level (2½-3") than other varieties. P.Dell tubers were formed particularly deep (6"-8"). The variety K.Edward succumbed earlier to blight (20th September) than Majestic and Redskin and all three had a much shorter growing season than P.Dell, G.Wonder and K.Pink, the haulms of which remained fairly green until the start of lifting in mid-October. In general the initiation of tuber formation was in the following order:-

K.Edward, Majestic, Redskin, K.Pink, P.Dell, G.Wonder.

The relatively later formation of tubers of G.Wonder was very noticeable.

In addition to blight incidence mentioned above, tubers of the varieties Redskin, K.Pink, K.Edward and P.Dell were badly affected by Common Scab disease (*Streptomyces scabies* (Thax.)) on the sandier soil at Langhill. The only other important disease recorded was 'Blackleg' (*Pectobacterium carotovorum* Var. atrosepticum), and the most susceptible variety appeared to be Majestic.

Plant-Soil Samples

A comparison of the number of slugs found next to the tubers of the

Table 36

Mean Slug Counts in ~~Plant~~-Soil Samples from 6 potato varieties

(Transformed Data)

Site - Species	Redskin	K.Pink	K.Edward	G.Wonder	Majestic	P.Dell	S.E. of Mean	Stat. Sig.
Beanston								
A.reticulatus	0.37	0.44	0.39	0.33	0.33	0.41	0.06	NS
A.hortensis	0.52	0.42	0.52	0.35	0.37	0.42	0.07	NS
A.fasciatus	0.34	0.32	0.28	0.28	0.28	0.28	0.03	NS
Total of 3 sp.	0.62	0.58	0.58	0.41	0.41	0.53	0.09	NS
Langhill								
A.reticulatus	0.44	0.36	0.40	0.32	0.44	0.37	0.04	NS
A.hortensis	0.31	0.31	0.29	0.29	0.33	0.33	0.02	NS
A.fasciatus	0.34	0.32	0.36	0.30	0.34	0.35	0.02	NS
Total of 3 sp.	0.51	0.41	0.48	0.34	0.54	0.50	0.05	*
Gateside Sample 1)								
A.reticulatus	0.47	0.47	0.45	0.47	0.52	0.43	0.05	NS
A.hortensis	0.49	0.59	0.59	0.46	0.54	0.55	0.05	NS
A.fasciatus	0.28	0.36	0.34	0.33	0.32	0.41	0.03	NS
Total of 3 sp.	0.66	0.72	0.73	0.63	0.71	0.67	0.06	NS
Gateside Sample 2)								
A.reticulatus	0.45	0.36	0.42	0.51	0.54	0.44	0.06	NS
A.hortensis	0.50	0.58	0.43	0.65	0.45	0.61	0.05	*
A.fasciatus	0.33	0.35	0.37	0.41	0.35	0.44	0.05	NS
Total of 3 sp.	0.66	0.67	0.63	0.85	0.69	0.76	0.06	NS

Table 37

Tuber damage in plant-soil samples from 6 potato varieties

(Transformed data)

Damage factor - Site	Redskin	K.Pink	K.Edward	G.Wonder	Majestic	P.Dell	S.E. of Mean	
% of tubers damaged								
Beanston	27.9	10.2	8.4	0.0	8.8	6.0	6.4	NS
Langhill	19.2	31.4	13.9	8.4	10.0	8.1	5.2	*
Gateside 1)	34.7	11.2	19.8	25.1	1.3	3.0	5.5	***
2)	10.0	12.5	10.7	8.5	15.9	11.0	7.6	NS
Total slug holes								
Beanston	0.77	0.21	0.12	0.00	0.25	0.12	0.15	*
Langhill	0.46	0.46	0.29	0.20	0.20	0.15	0.09	NS
Gateside 1)	0.74	0.21	0.35	0.49	0.01	0.06	0.11	***
2)	0.17	0.25	0.24	0.18	0.31	0.23	0.15	NS
Holes per damaged tuber								
Beanston	0.48	0.12	0.10	0.00	0.25	0.08	0.11	NS
Langhill	0.26	0.27	0.25	0.14	0.13	0.11	0.06	NS
Gateside 1)	0.42	0.11	0.18	0.27	0.04	0.04	0.06	NS
2)	0.50	0.34	0.37	0.35	0.42	0.31	0.04	NS

six varieties (Table 36) showed that at the time of sampling there was no consistent significant difference in the numbers of the three species. There were significantly more A. hortensis ($P > 0.5$) on P.Dell and G.Wonder than K.Edward in one sample only (Gateside). Analysis of the total of the three species showed a significant difference between varieties ($P > 5.0$) in the Langhill sample, in which the G.Wonder sample units had the least number and Majestic the highest number of slugs.(See Section A for details on populations.)

Comparison between plant-soil, field, and washed tuber estimates of damage

The results of the plant-soil sample (Table 37) show that it did not give a very accurate estimate compared with that of the more thorough field and washed tuber examinations (Tables 38, 39). Thus it is overestimated damage to Redskin and underestimated damage to G. Wonder at Beanston; overestimated percentage tuber damage to K.Pink and holes-per-tuber of Redskin at Langhill and underestimated the damage to K.Edward, K.Pink, P.Dell and Majestic at Gateside. However, the plant-soil sample did indicate that generally, tuber damage to the varieties Redskin, K.Pink, K.Edward and G.Wonder was considerably greater than to the varieties Majestic and P.Dell.

The field and washed tuber examinations at the Langhill trial show that the former gave reasonable estimates of damage on Redskin and K.Pink but considerably underestimated the damage to the remaining four varieties. This was probably because a lot more of the tubers of these four varieties had very few holes and were therefore overlooked in the very muddy conditions.

A Comparison of tuber damage at the three trial sites from the field and washed tuber examinations (Tables 38 and 39, and Fig. 7)

The sequence of varieties in order of severity of damage were not

Table 38

Numerical Assessment of Slug Damage to ware and seed from field and washed tuber examinations

(Transformed data)

Damage factor - Site	Redskin	K.Pink	K.Edward	G.Wonder	Majestic	P.Dell	S.E. of Mean	Stat. sign.
% Plant Damage								
Beanston (field)	37.4	23.0	25.9	25.6	11.9	14.3	2.3	***
Langhill (field)	43.8	45.6	23.9	18.1	11.6	5.6	5.5	***
% Tuber Damage								
Beanston (field)	14.9	7.5	8.0	10.3	3.8	5.3	3.7	***
Langhill (field)	18.2	19.4	9.1	7.6	4.1	2.3	2.3	***
Langhill (washed)	22.5	22.1	16.8	12.8	7.9	11.2	1.3	***
Gateside "	36.3	23.1	32.9	26.0	16.3	14.6	2.1	***
Total Slug holes								
Beanston (field)	1.1	0.7	0.7	0.9	0.3	0.4	0.1	***
Langhill (field)	1.3	1.4	0.7	0.6	0.3	0.1	0.7	***
Langhill(washed)	1.6	1.7	1.3	0.9	0.6	0.5	0.1	***
Gateside "	1.8	1.4	1.7	1.5	0.9	0.7	0.08	***
Holes per Damaged Tuber								
Beanston (field)	0.35	0.38	0.31	0.35	0.21	0.30	0.05	NS
Langhill (field)	0.46	0.40	0.20	0.35	0.18	0.08	0.06	***
Langhill(washed)	0.47	0.51	0.38	0.34	0.31	0.31	0.02	***
Gateside "	0.46	0.43	0.43	0.46	0.35	0.32	0.03	***

Table 39

Assessment by weight (in lbs) of damage to ware and seed

from the examination of washed tubers

(Transformed data)

Damage factor - site	Redskin	K.Pink	K.Edward	G.Wonder	Majestic	P.Dell	S.E. of Mean	Stat. Sign.
1) % weight of damaged tubers								
Langhill	25.8	24.7	18.3	14.8	8.9	10.0	1.7	***
Gateside	35.2	24.8	32.5	26.8	18.5	15.6	1.9	***
2) % weight of rejects per total tuber weight								
Langhill	10.0	11.9	7.9	1.9	1.2	2.3	1.9	***
Gateside	18.5	8.0	19.2	11.9	4.4	0.0	2.4	***

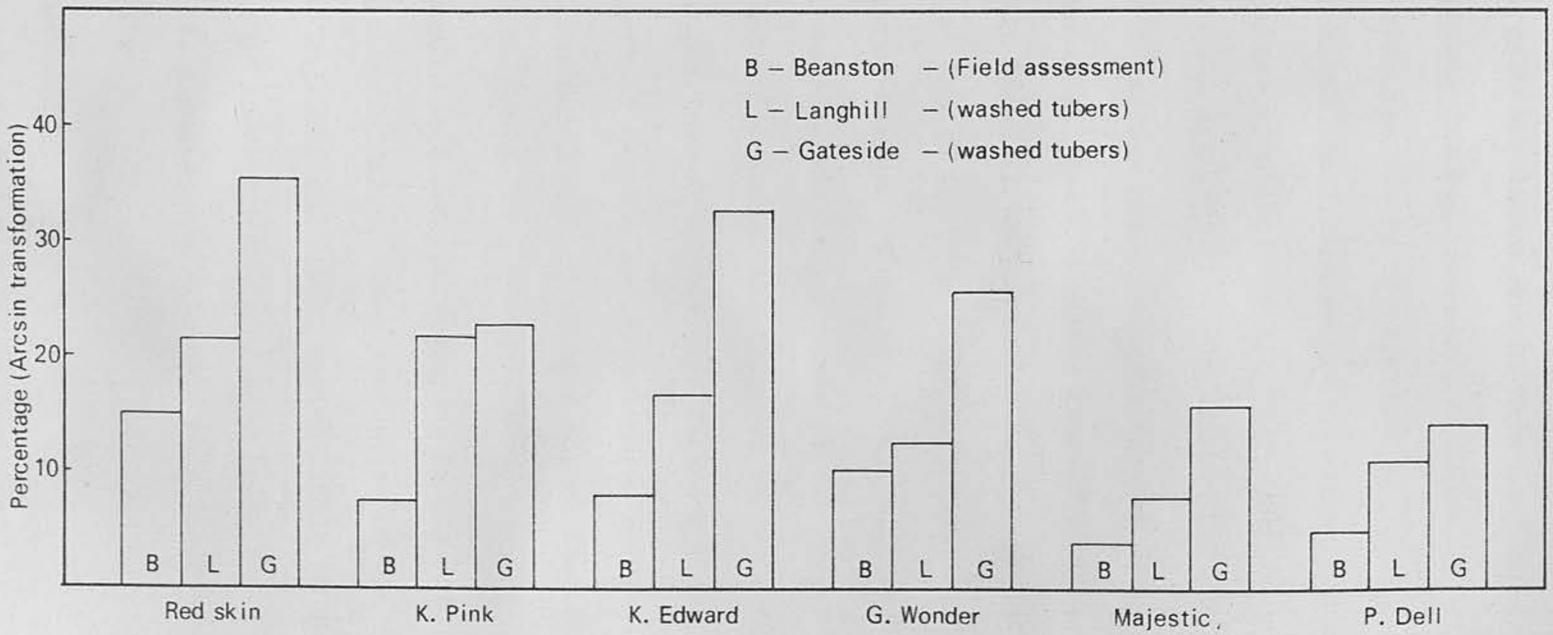


Fig 7 Percentage of Total Tubers damaged at the 3 sites

the same at each site, though the varieties Redskin, K.Pink, K.Edward and G.Wonder always suffered more damage than Majestic and P.Dell. Redskin usually had the greatest damage and P. Dell the least.

Percentage of plants damaged (Beanston, Langhill)

The varieties can be broadly divided into the two groups mentioned. Redskin at both sites and K.Pink at one site only had from three to eight times the percentage of plants damaged than Majestic or P.Dell.

Percentage of tubers damaged

Redskin had the greatest percentage of damaged tubers at two sites (Beanston and Gateside) being followed closely by G.Wonder and K.Edward respectively. At Langhill the varieties Redskin and K.Pink had an equally greater amount of damage than the other varieties. Majestic and P.Dell had the least number of damaged tubers at all three sites, their respective positions interchanging slightly at each site. Damage to the three varieties K.Pink, K. Edward and G.Wonder was the most variable between sites and only at Langhill was the latter variety significantly less than the two former varieties. Generally Redskin and occasionally K.Pink, K.Edward and G.Wonder, had over twice the percentage of damaged tubers than Majestic and P.Dell.

Slug Holes

Although there were interchanges in the relative positions of the varieties at each trial site, those varieities at the extremes of the range, namely Redskin, Majestic and P.Dell varied little in position and the same general pattern of greater numbers of slug holes on the four varieties (Redskin, K.Pink, K.Edward and G.Wonder) than (Majestic and P.Dell) was apparent.

Holes per damaged tuber

This measure of the severity of damaged tubers showed significant differences between varieties only at Gateside and Langhill. At Beanston K.Pink had the most severely damaged tubers, being closely followed by Redskin and G.Wonder whilst at Langhill K.Pink and Redskin both had equally the most severely damaged tubers. Severity of damage to Redskin, K.Pink, K.Edward and G.Wonder was the same at Gateside, being significantly greater than that to Majestic and G.Wonder.

Percentage Weight of Damaged Tubers

At Langhill the varieties Redskin and K.Pink had the highest (equal) percentage weight of damaged tubers compared with that of Redskin and K.Edward at Gateside. The different respective values of the three varieties K.Pink, K.Edward and G.Wonder at the two sites is noticeable,thus K.Pink had a significantly greater value than the other two varieties at Langhill whilst K.Edward had the significantly greater value at Gateside.

Percentage Weight of Rejects

The data showed very similar trends to the above, with the exception that the variety K.Edward did not have a significantly lower value than Redskin and K.Pink at Langhill.

Economic Crop Loss due to Varietal Susceptibility

The estimated varietal ware crop losses at Langhill and Gateside in terms of percentage reject weight loss per 10 ton crop and the approximate corresponding financial loss based on the price - payment ranges shown (Table 40) demonstrate that there would have been considerable differences in financial loss between some varieties and to a lesser degree within any one variety at the two sites.

Table 40

Estimated Ware Crop Losses at Two Sites
(Detransformed data)

Variety	Percentage of Reject Tubers in lbs weight		Weight of Reject Tubers in cwts. per 10 ton crop		Approx. Cost of Loss per 10 ton crop		Price Payment Range per ton ware
	Langhill	Gateside	Langhill	Gateside	Langhill	Gateside	£
Redskin	3.50	9.70	7.50	20.00	£5- £9	£15 - £25	15 - 25
K.Pink	5.60	2.20	10.00	5.00	£7-£13	£ 4 - £ 6	16 - 26
K.Edward	2.40	11.40	5.00	20.00	£4-£ 6	£15 - £25	15 - 25
G.Wonder	0.14	5.30	0.29	10.00	6s -10s	£10 - £15	20 - 30
Majestic	0.05	0.71	0.11	1.43	1s - 2s	17s - 36s	10 - 20
P.Dell	0.19	0.00	0.38	0.00	0	0	10 - 20

Part 2 - Laboratory Investigations

Introduction

The experiments included tests with individual tubers of the six varieties placed in containers together with slugs of different species to assess the feeding behaviour and possible preferences of the separate slug species. Cut, sliced and cores of tubers were used in tests to ascertain the attractiveness and palatability of the potato flesh alone without the skin barrier. Sugar analysis tests were made on tubers together with penetrometer tests on the skins of whole tubers in an attempt to correlate possible differences with susceptibility. Comparative tests were also made between the palatability of old and young leaves of the variety Redskin and between mature leaves of the varieties Redskin and Majestic (two extremes of susceptibility) because field observations had indicated possible differences in the susceptibility of leaves as well as tubers.

Examination of the data of other research workers studying the potato, more directly, for such properties as sugar content, skin thickness, skin strength etc., was made in order to collect more specialised data on botanical aspects of the varieties in question.

Materials and Methods

Experiment (a) Whole Tubers and Slugs (Pilot Experiment)

One small whole undamaged tuber of each of the six varieties, lifted from the Gateside trial a few days previously, was placed on damp filter paper in two small plastic containers measuring 4" x 10" (having gauze ventilation in the lid). Twenty full grown adult slugs of the species *A. reticulatus* and *A. hortensis* were placed separately (at random) in the two containers and kept in a dark cupboard with an ambient temperature of $20^{\circ}C \pm 2^{\circ}C$. The tubers were examined after the first night, and then after an interval of two days, daily for seven days and the numbers and size of slug holes in the tubers recorded. The tubers were kept moist by spraying with water after each examination.

(b) Whole tubers with slugs (replicated experiment)

A larger replicated trial was carried out using tubers from Gateside that had been lifted for six weeks and stored in the cold ($8^{\circ}C$-$10^{\circ}C$). Each replicate consisted of one small undamaged tuber of each variety placed in a 2" deep biscuit tin with ten slugs ($8^{\circ}C$-$10^{\circ}C$). Four replicates for each of the three species A. reticulatus, A. hortensis and A. fasciatus were set up.

The trial lasted for four nights and inspections of tuber damage were made on alternate days in order to keep the tubers damp, remove and replace any dead slugs and record damage to the tubers.

(c) Whole tubers and sliced tubers

Ten adult A. reticulatus and A. hortensis were housed in one plastic container with one undamaged tuber (approximately 1.5" diameter) and an $\frac{1}{8}$" thick tuber slice of each potato variety. The container was kept in the dark at $20^{\circ}C \pm 2^{\circ}C$ for seven days with daily inspections to keep the slices damp by spraying with water. After this period an assessment of damage was made on an arbitrary visual scale. A similar test using tuber slices only was carried out in two containers with twenty adult A. reticulatus in one and twenty A. hortensis in the other.

(d) Tuber cores

A small core was taken from a tuber of each of the six potato varieties with a $\frac{1}{4}$" diameter cork borer. The cores were placed on damp filter paper in a plastic box with ten large adult A. reticulatus. The box was left for two days in the dark at a room temperature of approximately 20°C. By using these fairly narrow cores the difference between the amounts of tuber flesh eaten can easily be seen. Initial weights of the cores were taken, in water, and volume displacement measurements were taken in small graduated cylinders before and after the experimental period.

(e) Sugar Content of Tubers

Tuber cores from the same batch of six varieties used in the replicated whole tuber trial were prepared for sugar analysis by the following technique. A known fresh weight (approximately 25 g) of tuber, was taken in the form of four cores, one from each of four tubers of each variety and placed in six conical flasks, each containing 200 ml of industrial spirit and 100 g of Calcium Carbonate. The mixture was brought to the boil and stored in a refrigerator. The sugar analysis was made on the ground preparation of the cores.

(f) Penetrometer Tests on the Skins of Whole Tubers

Penetrometer Tests were made on whole tubers lifted from the Gateside Trial site. The tests were performed at the National Institute of Agricultural Engineering situated at the College Centre of Rural Economy. The penetrometer is a standard piece of apparatus used to test the skin strength of tubers using the simple principle of increasing the load on a given surface area contact between a small flat ended cylinder of known cross-sectional area and a chosen point on the tuber. The reading given at the point of rupture of the skin is termed the Lampé reading and tests were carried out on one wet and one dry tuber of the six varieties at four positions on each tuber.

(g) Skin Thickness and Crude Fibre Content

Information on these properties of the tubers of different potato varieties including K.Edward, Majestic, K.Pink, Redskin and G.Wonder were obtained from the work of E. Nagdy (Ph.D thesis, Edinburgh).

(h) Potato Leaf Damage

Semi-mature leaves were cut from pot grown plants of Majestic and Redskin. Two leaves of each variety were placed on damp filter paper in 20 plastic boxes with the dorsal surface of the leaf facing uppermost. Four large adult slugs (400-500 mg) of the species A. reticulatus and A. fasciatus were placed separately in each of 10 boxes, giving ten replicates per slug species. The boxes (with top gauze ventilation) were kept in an outside insectary at a temperature range of between 8°C-10°C in July (1968). After three nights the leaves were examined and recorded for comparative damage (see Section A).

A second experiment was set up with young and mature leaves of Redskin and four adult A. reticulatus in each of eight replicates per treatment.

Results and Discussion

(a) Whole Tubers and Slugs (pilot test)

Table 41 shows the amount of damage to the tubers and the positions of the slugs after each examination. The species A. reticulatus quickly made holes in the tubers of the varieties K.Edward, K.Pink, Redskin and Majestic, the former having the most holes and the latter the least. There were more slugs next to these damaged tubers. A. hortensis made no holes in the tubers on the first night and there were more slugs adjacent to the G.Wonder tuber than others. After three nights the A. hortensis had started to attack the

Table 41

Progressive damage to 6 tuber varieties over 7 days and the location of the slugs

Time Interval - Slug species	Redskin		K.Pink		K.Edward		G.Wonder		Majestic		P.Dell	
	Holes	Slugs near tuber	Holes	Slugs near tuber	Holes	Slugs near tuber	Holes	Slugs near tuber	Holes	Slugs near tuber	Holes	Slugs near tuber
After 16 hrs												
A.reticulatus	2^{+}	4	1^{+} 2^{ϕ}	3	5^{ϕ}	3	0	2	1	3	0	1
A.hortensis	0	2	0	3	0	2	0	6	0	3	0	1
After 72 hrs												
A.reticulatus	2^{+}	2	1^{+} 2^{ϕ}		4^{+} 2^{ϕ}	4	0	3	1^{+}	0	$1^{\mp}$	1
A.hortensis	5^{ϕ}	4	0	2	1^{+}	4	0	0	1^{ϕ}	0	0	2
After 168 hrs												
A.reticulatus	2^{+}	-	1^{+} 2^{ϕ}		4^{+} 2^{ϕ} $2^{\mp}$	-	1^{ϕ}	-	1^{+}		$1^{\mp}$	
A.hortensis	5^{ϕ}	-	2^{ϕ}		1^{+}		1^{ϕ} $1^{\mp}$		1^{+} 1^{ϕ}		$2^{\mp}$	

ϕ = small $\quad$ + = large $\quad$ $\mp$ = abrasion

Table 42

Damage to whole tubers by three slug species

Variety / Species	Mean number of holes per tuber							
	Redskin	K.Pink	K.Edward	G.Wonder	Majestic	P.Dell	S.E. of Mean	Stat: sig:
A.reticulatus	0.97	1.35	1.00	0.93	0.84	0.97	0.21	NS
A.hortensis	0.97	0.84	0.84	0.97	0.71	0.84	0.14	NS
A.fasciatus	0.97	0.84	0.97	0.97	0.71	0.71	0.12	NS

Table 43

Damage to whole and sliced tubers by A. reticulatus

Variety	Redskin	K.Pink	K.Edward	G.Wonder	Majestic	P.Dell
Whole tubers (holes)	0	0	3	0	0	0
Tuber slices (scale 0-10)	5	6	6	6	3	1
Tuber slice alone	6	6	6	6	4	3

tubers, and the variety Redskin had by far the most holes, (5 small), K.Edward having one large hole and Majestic a small hole. The species A. reticulatus had made only two further fresh holes, one on the K.Edward and one small abrasion on the P.Dell tuber whilst most of the existing holes on the other damaged tubers had been enlarged. This increasing excavation of existing holes continued until the end of the seven days with the exception that both of the slug groups (A. hortensis and A. reticulatus) made a very small abrasion on the two G.Wonder tubers after four and six days respectively. Thus the species A. reticulatus caused greater damage to the tubers of K.Edward, K.Pink and Redskin (in that order) than the varieties G.Wonder, Majestic and P.Dell. The species A. hortensis though also causing greater damage to the first group, as mentioned above, inflicted the greatest damage on the Redskin tuber and less damage to the K.Edward tubers.

(b) Whole tubers and slugs

Table 42 shows the total damage at the end of four days. The damage was recorded as definite 'holes', or 'superficial' damage where only slight skin abrasions were made. The analysis of variance shows that there was no significant difference in damage between the six varieties for any of the four species though the previous trend of more damage on the varieties K.Pink, Redskin, K.Edward and G.Wonder than on Majestic and P.Dell was repeated. The slug species A. reticulatus appeared to attack the tubers more actively than A. hortensis and A. fasciatus (see means).

(c) Whole and sliced tubers

Table 43 shows that at the end of the first test period, the only whole tuber with damage was that of the variety K.Edward whereas damage on the tuber slices was far greater. Majestic and P.Dell tubers were damaged much less than the other four varieties.

Damage to Tuber Slices
(arbitrary scale, 0-10)

Species	Redskin	K.Pink	K.Edward	G.Wonder	Majestic	P.Dell
A. reticulatus	6	6	10	7	7	3
A. hortensis	8	7	8	2	3	2
Total	14	13	18	9	10	5

The above table shows that whilst the A. hortensis apparently favoured the varieties Redskin, K.Pink and K.Edward the A. reticulatus were less discriminate in their choice though K.Edward was damaged to the greatest extent and P.Dell the least.

(d) Tuber Cores

The order of damage to the cores is shown (Table 44) from a combination of the measure of the volume and weight of devoured tuber. The results agree with the previous test, with the exception that the amount of Redskin tuber eaten was unexpectedly small. The apparent increase in the weight of the damaged cores of P.Dell and Redskin was due to water uptake, emphasised by the small amount eaten.

(e) Sugar Content of Tubers

Table 45 shows the results of the sugar analysis on the six varieties. The two less susceptible varieties, Majestic and P.Dell, had by far the higher amount of the total sugars present, both as reducing sugars and as sucrose.

Table 44

Damage to cores of tuber flesh by A. reticulatus

Potato Variety	Redskin	K.Pink	K.Edward	G.Wonder	Majestic	P.Dell
Volume eaten (mls) (by water displacement)	0.08	0.65	0.20	0.30	0.10	0.10
Weight eaten (grammes)	+0.12	-0.75	-0.54	-0.15	-0.20	+0.22

Table 45

Sugar content of potato tuber flesh

Potato Variety	Total Sugar (as glucose) mg/100 g	Reducing Sugar (as glucose) mg/100 g	Sucrose mg/ 100 g
Redskin	497	377	119
K.Pink	575	411	160
K.Edward	444	278	162
G.Wonder	540	379	158
Majestic	870	509	354
P.Dell	1050	705	341

Table 46

Lampé readings from penetrometer tests on wet and dry tubers of 6 varieties

Variety \ Test positions		1	2	3	4	Mean
Redskin	1) wet	51.0	39.1	37.5	42.3	42.7
	2) dry	37.6	39.7	41.4	35.1	38.4
K.Pink	1) wet	34.3	38.4	32.7	35.8	35.3
	2) dry	33.4	29.8	31.3	38.4	33.2
K.Edward	1) wet	41.0	46.9	43.9	42.9	43.6
	2) dry	38.0	41.7	48.2	36.0	41.1
G.Wonder	1) wet	46.5	45.8	50.0	43.4	46.4
	2) dry	39.4	47.0	40.0	41.6	42.0
Majestic	1) wet	32.5	30.6	30.0	28.4	30.4
	2) dry	35.1	39.4	31.2	38.6	36.1
P.Dell	1) wet	35.8	38.7	38.2	42.9	38.9
	2) dry	42.6	47.1	47.7	39.9	44.3

(f) Penetrometer Tests on Whole Tuber Skins

The four Lampé readings for each wet and dry tuber with mean values are given in Table 46. The dry tubers of Majestic and P. Dell showed slightly stronger skin resistance, the vice versa being true for the other four varieties. The variation in readings for one single tuber were quite wide. The mean values show that the varieties G. Wonder, K. Edward and P. Dell had slightly stronger skins than Redskin and considerably stronger skins than the varieties Majestic and K. Pink (see also Table 2C).

(g) Potato Leaf Damage

Mature Redskin and Majestic Leaves

Table 47 shows the leaf areas eaten in each replicate for each of the two slug species. The analysis of variance (a paired T test on the difference between the values of log (X + 1) where X = leaf area), showed no significant difference between the two varieties for both species though approximately twice as much total leaf area of Redskin than Majestic was eaten by both species. A. reticulatus ate approximately eight times more total leaf area than A. fasciatus. Plate 1 shows damage to some leaves of the two varieties in the test.

Mature and Young Redskin Leaves

A similar analysis of the amounts of young and old Redskin leaves eaten in three nights by A. reticulatus (Table 48) shows that there was a significantly larger area of the older leaves eaten. Again there was approximately twice the area consumed of older leaf than younger leaf by A.reticulatus. Plate 2 shows damage to some young and mature leaves in the test.

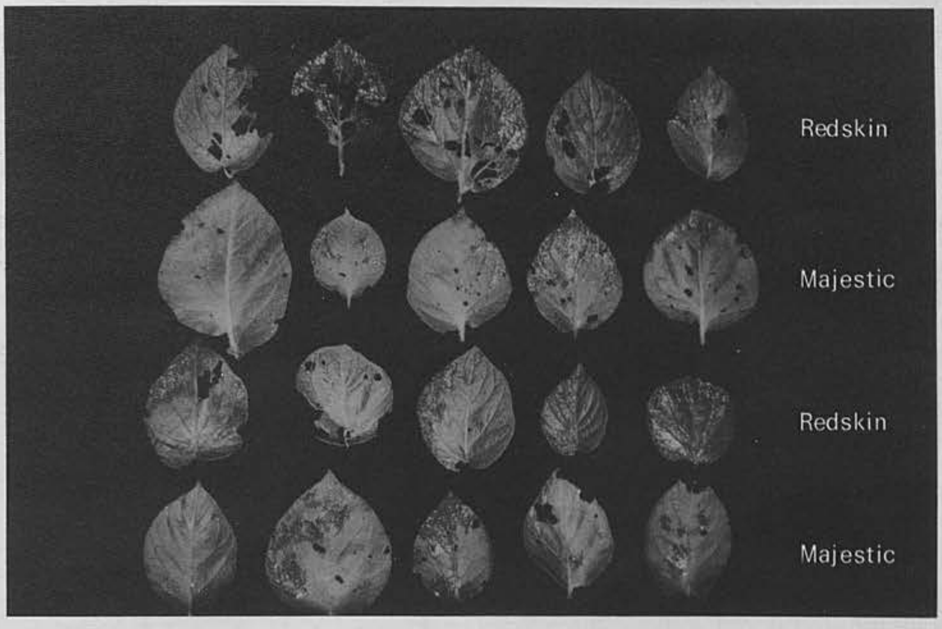


Plate 1 Slug damage to potato leaves of the two varieties Redskin and Majestic

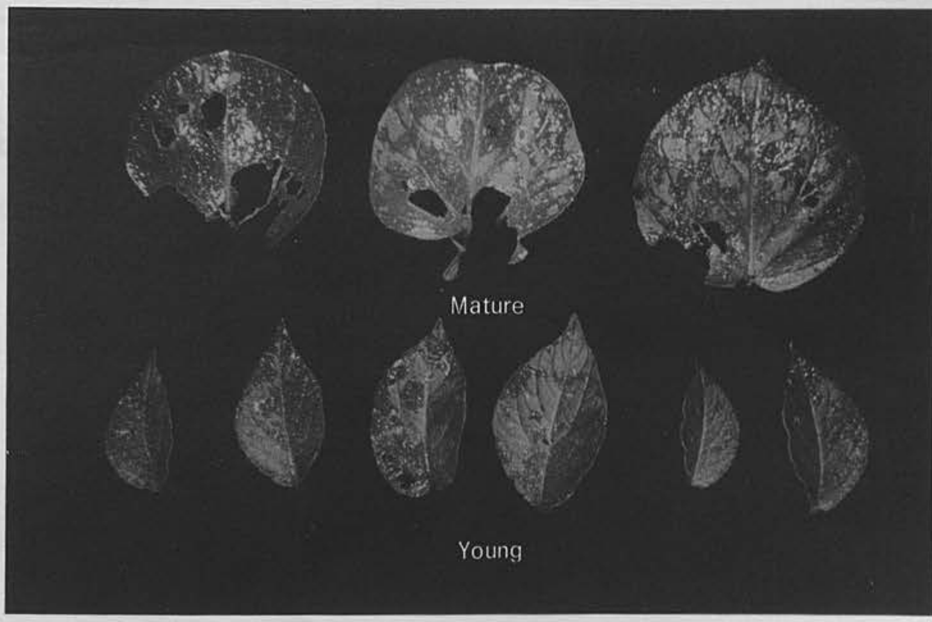


Plate 2 Slug damage to young and mature potato leaves of the variety Redskin

Table 47

Amounts of potato leaf area eaten by two slug species

(transformation - log (x + 1))

Slug Species	A. reticulatus			A. fasciatus		
Potato Variety	Redskin	Majestic	Difference	Redskin	Majestic	Difference
Replicates 1	1.83	0.78	1.05	0.60	0.48	0.13
2	2.00	0.69	1.31	1.04	0.10	0.94
3	1.70	0.69	1.00	1.00	0.24	0.76
4	1.40	0.95	0.44	0.48	0.10	0.38
5	0.90	1.11	-0.21	0.65	0.48	0.18
6	0.48	0.85	-0.37	0.78	0.48	0.30
7	1.32	0.00	1.32	0.48	0.39	0.10
8	1.51	0.78	0.73	0.00	0.18	-0.18
9	0.54	1.18	-0.63	0.60	0.48	0.13
10	0.00	1.54	-1.54	0.30	0.60	-0.30
Total Difference =			3.09	Total Difference =		2.41
Mean Difference =			0.31	Mean Difference =		0.24
"t" value =			0.55(NS)	"t" value =		0.65(NS)

Table 48

Amounts of young and mature Redskin potato leaf area eaten by A. reticulatus (transformation - log (x + 1))

Leaf Age	Mature	Young	Difference	Mature	Young	Difference
Replicates						
1	1.38	0.00	1.38	1.36	0.30	1.06
2	1.49	0.30	1.19	1.92	0.30	1.62
3	1.77	0.48	1.29	1.86	0.40	1.46
4	1.52	0.30	1.22	1.26	0.60	0.65
5	1.56	0.48	1.08	1.49	0.00	1.49
6	1.38	0.60	0.78	1.72	0.48	1.24
7	1.15	0.18	0.97	1.66	0.48	1.19
8	1.78	0.30	1.48	1.83	0.30	1.53
	Total Difference =		9.38	Total Difference =		10.24
	Mean Difference =		1.17	Mean Difference =		1.28
	"t" value =		5.19***	"t" value =		3.36***

Discussion on varietal susceptibility

Replicated field trials on a range of soil types, with different weather conditions, slug population densities and species complexities showed that the varieties Redskin, K.Pink, K.Edward and G.Wonder were considerably more susceptible to slug attack than the varieties Majestic and P.Dell. The variety consistently sustaining the greatest damage was Redskin and the least P.Dell. The severity of damage to the varieties K.Pink, K.Edward and G.Wonder differed considerably in relation to one another at the three sites. This may have been due to differences in their relative susceptibility and or palatability caused possibly by one or more of the following factors:-

(a) Differences in maturity (Thomas 1947) at the sites due to

i) Different sampling dates. Thus the later maturing variety G.Wonder was more heavily damaged at Gateside (latest lift).

ii) Length of time following haulm destruction. Thus the more severe blight attack at Gateside killed off the haulms of K.Edward and Majestic considerably earlier than at the other two sites. The variety K.Edward especially, had relatively more damage at this site than elsewhere.

(b) Difference in soil moisture at the sites due to weather and soil type. Thus the wetter conditions at Gateside and to a much lesser extent at Langhill may have affected the palatability of some varieties (e.g. K.Pink) whilst aiding penetration and feeding on the thicker and tougher skinned variety G.Wonder.

The measurement of the numbers of plants damaged, slug holes and rejected tubers probably gave the best indication of the biological differences in varietal susceptibility and the extent of slug feeding activities on the six varieties.

The fact that the more susceptible varieties had a higher percentage of damaged plants did not mean that more slugs were attracted to them since the plant-soil samples showed that there was no consistent difference in the number of slugs adjacent to the tubers of any particular varieties at a time when slug feeding activity was high. It would have been reasonable to assume that larger numbers of slugs may have aggregated next to the tubers of the more susceptible varieties. However, even in the two instances where there were significantly greater numbers of slugs next to some varieties; the greater number of slugs were found adjacent to varieties suffering relatively less damage.

The fact that slugs feed more actively on tubers after haulm senescence (Carrick 1938) is of course correct. However, this does not seem to greatly affect varietal susceptibility since the haulms of the susceptible variety K.Pink and to a lesser extent G.Wonder remained green well into the autumn whilst the haulm of the less susceptible variety Majestic died off long before, due to blight infection,and Majestic is naturally an earlier maturing variety.

Though some varieties tended to produce more tubers per plant than others (e.g. K.Edward), this did not appear to influence the situation. Very rarely were all the tubers of any one plant damaged, so that 'availability' in terms of tuber number is discounted.

The small scale laboratory feeding preference trials with tubers showed that a similar differential attack on varieties occurred after removing all other possible environmental influences that may prevail in the field, including differential haulm cover, resulting from blight attack. The lack of statistical significance in some of the trials was probably due to the relatively short test period used and the wide variation naturally occurring in feeding trials. However, the trends in most cases were related to events recorded in the field.

Slugs appear to feed preferentially on the damaged or cut areas of tubers (cf Stephenson 1964) and it seems obvious that although the tuber skin forms some degree of barrier to slug damage, this preferential feeding is probably advanced by olfactory and gustatory attraction to the cut tuber surfaces. The fact that slugs often return to continue feeding on existing exposed feeding sites on the tuber, implies attraction to these sites and less 'willingness' to excavate further holes through the skin and relatively harder cortex region of the tuber, when exposed tuber flesh is 'available'.

Though the tuber periderm may form some mechanical barrier to slug attack, the data on varietal differences in skin thickness (Table 1C from Nagdy), skin strength and crude fibre content does not indicate any consistent relationship with varietal susceptibility. The thinner skinned varieties were not always the more susceptible varieties i.e. the variety Majestic had the thinnest skin and G.Wonder the thickest, and differences in thickness between Majestic and Redskin were slight. On average, Majestic also appears to have the lowest and G.Wonder the highest skin strength (see also the three years records of the National Institute of Agricultural Engineering (Table 2C, Appendix C) though there is obviously considerable variation within any one variety. The varieties Redskin, K.Pink and K.Edward had the lowest percentage of crude fibre in the skin but conversely G.Wonder had a higher percentage than Majestic and yet suffered greater damage.

The observations of Miss.B.Eaton (personal communication), in which slugs were seen to feed preferentially on sugars to starch (sucrose especially) does not appear to agree with the results obtained here, whereby the least susceptible varieties had the greater total sugar content. Table 3C

(Appendix C) shows the results of sugar tests taken one week after harvesting tubers of the three varieties K.Edward, Majestic and G.Wonder by W.G. Burton (1965). The value for K.Edward was considerably lower than that for the other two varieties (cf results of sugar analysis made by the author). He states, from the evidence of his research that though little detailed work has been carried out on the varietal differences in sugar content, the following is generally true:-

i) Immature tubers have a higher sucrose content than mature tubers.

ii) Mature tubers of all varieties have a very variable sugar content at harvest.

iii) The maximum sweetening of tubers occurs at low temperature.

iv) The magnitude of sweetening shows considerable varietal difference.

There was no evidence to suggest that the three slug species have different varietal preferences, though the species A. reticulatus appeared to be less discriminate in its feeding. Hence the varying differences in susceptibility of some varieties at the three sites would not appear to be caused by the relative differences in the numbers of each species present (e.g. low population of A. hortensis and high population of A. fasciatus at Langhill).

It is suggested that there are two main possibilities which may occur, either individually or in conjunction, to produce this difference in varietal susceptibility:-

(1) Some form of close range feeding attraction or stimulus, involving a favourable olfactory and/or gustatory stimulation elicitated by a substance(s), in the superficial cell layers (possibly also exudated on to the skin surface) of the entire plants of the more susceptible varieties, and/or,

(2) A substance(s) in the skin of the entire plant of the less suscept-

ible varieties which is repellent or distasteful to the olfactory and/or gustatory senses of the slugs, thus largely inhibiting initial feeding on these tubers.

If neither of the above occurred, and since there appeared to be no large scale locomotory attraction to the plants of susceptible varieties, then one would have expected to have found an equal number of tubers of all six varieties to have some degree of slug damage (even though the tuber flesh of separate varieties may have different palatabilities). This was not found to be the case and it is suggested that the greater, increase in damage to the susceptible varieties was due to prolonged, continuous feeding on a palatable food supply and the making of further fresh holes on affected and unaffected tubers of a susceptible variety because of this differential close range stimulus or absence of a feeding inhibitor. Thus, with an increase in time the relative difference in damage between the two variety groups tends to become greater.

It is suggested that field observations tend to support the hypothesis of a feeding inhibitory substance in the more resistant varieties. It seems unlikely that such omnivorous feeders as slugs do not attack the tubers of a resistant variety, after haulm destruction, (when there is little alternative nutritious food supply), simply because the tubers do not provide a positive stimulus to feed.

The preferential feeding on the older leaves of the variety Redskin suggests also the existence of attractive and/or repellent substance(s) in the differently aged leaves of a single variety. Generally, older leaves have a higher percentage of translocated sugars than younger leaves whilst the former possess numerous, different chemical compounds associated with a high rate of cell division and metabolism. This apparent rejection of the young leaves was also observed in a large container housing a number of slugs of the following species - A. fasciatus, A. hortensis, A. reticulatus, M. budapestensis and Helix aspersa Müller, and a sprouting tuber of the variety K.Edward. On numerous occasions slugs of each species and the snails were seen on the growing aerial shoots (3-4" high); but even in the absence of an alternative food supply no feeding occurred on the shoots and very young leaves over a period of three weeks. This again suggests that feeding was actively inhibited by a repellent substance. It therefore seems likely that there may be a positive correlation between the lower incidence of damage to newly formed potato tubers (see Thomas 1947) and to young leaves.

The economic implications of varietal susceptibility can be great. The more susceptible varieties studied here are widely grown for ware in South East Scotland because of their greater popularity, and they thus generally command higher prices. Even though differential payments are not yet made for higher quality, slug-hole-free crops; they tend to be rejected, especially in periods of ample supply. The data from the crops grown at the two sites show that even under conditions of moderate damage, rejected tuber losses can be as high as 2 cwt. of ware per ton for a susceptible variety like Redskin. This is equivalent to £15 per acre for a 10 ton ware crop per acre, whereas losses with a non-susceptible variety, such as P.Dell, can be zero when grown under identical conditions. This refers only to badly damaged rejected tubers and does not take into account the greater majority of less severely damaged tubers which are not acceptable as high quality produce for the more profitable pre-packed market.

SECTION E

SOME FACTORS AFFECTING CROP DAMAGE

Introduction

Whilst carrying out the major field trials in this investigation, a number of observations and short trials were made, together with laboratory tests, in order to obtain further information on the various different biological and environmental factors contributing to the aetiology of slug damage on potato crops.

Materials and Methods

Slug species causing tuber damage

Records were kept of the slug species found adjacent to tuber samples in the various field trials, and in many cases, slugs recovered from plant-soil samples were housed separately in petri dishes and their faeces tested for potato starch with iodine solution.

Size and maturity of slugs causing tuber damage

Three undamaged Redskin tubers were housed separately with ten slugs of each of the four different weight categories of the three species (see page 103) in six ventilated plastic boxes for seven days. A visual appraisal of damage to the tubers was made.

The distribution and movement of slugs in the potato crop

1) Surface activity

The surface activity of slugs in the potato crop over the cropping period was assessed from the response to slug pellet strips and traps, placed in various crops during the course of the investigations.

2) Subterranean activity

The distribution of slugs in the ridge and an examination of the ridge environment of a potato crop of the variety Redskin was investigated by carefully exposing numerous cross sectional areas of the ridge and making visual observations.

Further information on the nature of the ridge environment was obtained as follows. Molten paraffin wax was poured down ridge crevices, adjacent to plant stems. After allowing time for the wax to solidify, a 5" deep plant-soil sample was taken and the soil carefully washed away from the wax to give a three-dimensional assessment of the subterranean cavities and interstices.

3) Self marking experiment

An experiment was carried out to determine whether slugs use the cavities in the ridge as daytime resting sites after nocturnal feeding activities on the soil surface. Bran, dyed with Mason's green was placed in petri dishes adjacent to six plants on the ridge top for one night in the above Redskin crop. The following day the ridge soil around these plants was carefully removed and any slugs found examined for evidence of the dye in the gut (visible through the foot). Laboratory tests on the feeding of dyed bran to slugs of the species A. reticulatus had shown that the dye remained visible in the gut for up to two weeks after feeding.

Crop husbandry and cultivation

i) Planting depth

A small trial was carried out on a garden allotment on which slugs of the species A. reticulatus, A. hortensis, A. fasciatus and M. budapestensis had been found. The allotment consisted of five rows of seven, 2 yd x 2 yd plots, each separated by 1 ft. wide paths of grass. Four Redskin tuber setts were planted per plot, two at a depth of 6" and two at a depth of 2" on the 6th June 1966. The daughter tubers of each plant were inspected for damage on the 30th September and any tuber with one or more slug holes recorded as a damaged tuber.

ii) Early versus late removal of haulm

The inspection of a crop of the variety Redskin (Beanston 1967) that had been irrigated in early August, revealed considerable leaf damage. This, together with the fact that slugs were present next to the tubers (though not causing significant damage) prompted an experiment to compare the possible effect on slug damage of early and late destruction of the haulm and weed vegetation.

A sixteen plot trial, each plot measuring 36' x 36' was set up. The control and treated plots were randomised in pairs, and the haulm desiccated on the treated plots with 'Reglone' on the 4th September. By the 7th September the sprayed haulm and weeds were completely blackened and dry. Tuber samples were taken at approximately weekly intervals as follows:-

1. 4th September (control sample) 2. 13th September 3. 24th September
4. 3rd October 5. 11th October.

Each sample consisted of ten plants, examined in situ. Information on the density and distribution of slugs on the plots was obtained from a plant-soil and a furrow-soil sample taken on the 8th October.

Unfortunately, by mistake, all the sixteen plots were sprayed with sulphuric acid on the 29th September and by the 1st October the green haulm and weeds on the control plots were desiccated.

Records were kept of soil moisture changes in the ridge and furrow over the trial period, from soil moisture tensiometers placed 4" below the soil surface, in three control and three treated plots.

Results and Discussion

Slug species causing tuber damage

Slugs of the three species A. reticulatus, A. hortensis and A. fasciatus were found within or near to damaged tubers in the course of these investigations, whilst none of the Milax species were observed at the numerous field sites. Laboratory tests (Section D, page 136) showed that each of the three pest species was capable of penetrating and feeding upon whole tubers of the more susceptible varieties, in the absence of an alternative food supply. The results of iodine tests on the faeces of slugs (Table 49) showed that 31% of the A. reticulatus, 22% of the A. hortensis and 37% of the A. fasciatus recovered from soil samples had recently been feeding on potato tubers.

Discussion

It would appear from these observations that each of the three species are probably equally responsible for causing damage. However, it was seen that A. reticulatus was a more active surface feeder and that it continued to feed on aerial vegetation more frequently, and later into the autumn than the other two species. It is possible that the overall greater activity of this species, carried out both above and below the soil surface, results in an approximately equal amount of damage to that caused by the generally less active but more subterranean Arion species. This is not in agreement with the statements of other authors, including Thomas (1947), Edwards and Heath (1964) and Stephenson (1964) who have stated that A. reticulatus is not a primary pest on potato tubers and that it only increases the damage made principally by A. hortensis and/or M. budapestensis. The evidence presented here shows the reverse case to be the most likely in this region, with the more active A. reticulatus creating a greater number of entry holes into the tuber, which may then be excavated more continuously and persistently

Table 49

Tests for starch in slug faeces with iodine solution

Sample/Site-Date	Number of positive tests out of the total number examined		
	A. reticulatus	A. hortensis	A. fasciatus
1) Redskin crop Beanston 21.8.67	2/7	0/3	0/1
2) Redskin crop Beanston 4.9.67	1/44	2/55	0/0
3) Redskin Haulm Removal Expt. Beanston 11.10.67			
a) Untreated plots	1/5	3/15	0/2
b) Treated plots	2/4	8/15	1/4
4) Variety Trial Gateside 18.11.67	24/35	9/18	0/0
5) Redskin crop Beanston 19.10.67	1/1	11/29	2/3
6) Haulm Removal Trial			
a) Interplant	0/1	2/9	0/1
b) Plant-ridge	2/10	4/32	0/0
7) Redskin crop - Beanston			
a) Late pellet Application Trial 3.11.67	0/0	1/5	0/0
b) Variety Trial 3.11.67	1/8	2/9	0/0
8) Variety Trial Langhill	4/6	0/0	0/0
Total	38/121 = (31%)	42/191 = (22%)	3/11 = 37%)

by the Arion and Milax species. There would also appear to be very few sites in this region where A. reticulatus is not present together with other species.

It is realised however that differences may occur in different regions of Great Britain and that the pest status of individual species may vary, though this would seem unlikely in situations where all four species are present in any number. With reference to the importance of A. reticulatus as a pest on potatoes in the S.E. of Scotland, these results are in agreement basically with those of Carrick (1936). Though the population density of A. fasciatus was never found to approach that of A. reticulatus or A. hortensis it would appear to be more widely distributed than suggested by Carrick. It is interesting to note that Carrick recorded the fact that the species A. hortensis was relatively uncommon and that it had never been found attacking potatoes. Thus, either he missed observing this species, or its numbers have increased greatly over the last 30 years.

Size and maturity of slugs causing tuber damage

Slugs in the three heavier weight ranges (>25 mg) of the three pest species concerned made one or more definite penetrating holes into the potato tubers, whilst slugs in the lowest weight range (<25 mg) of each species made only very minor surface abrasions on the skins (periderm) of the tubers. From these observations it was concluded that only those slugs weighing over 25 mg were important contributors to potato tuber damage.

Distribution and movement of slugs in the crop

1) Surface activity

The response to the numerous test pellet strips, traps and bait pellet applications is demonstrated in the various field trials (see Sections A, D, F).

2) The ridge environment

The examination of the ridge in a crop of Redskins in late August revealed slugs of the three species A. reticulatus, A. hortensis and A. fasciatus resting near to and on the half grown tubers (Plate 3). At this time there was considerable damage to the leaves but very little damage to the tubers. The ridge soil was of a cloddy nature and there were numerous large cavities throughout the ridge and around the tubers (Plate 4). These air spaces were formed as a result of 1) the cloddy nature of the heavier textured soil, 2) the rotting and collapse of the parent tuber and 3) earthworm activity, evidenced by numerous burrows, with food stores, and casts throughout the ridge and especially in the region of the rotting parent tuber. Numerous deposits of green slug faeces were seen adjacent to the tubers, providing evidence of the prolonged use of the cavities and earthworm burrows (Plate 5) as daytime 'refuge' sites. In many cases these subterranean cavities were seen to connect with the soil surface via earthworm burrows, soil-clod interstices and usually via the spaces adjacent to the potato plant stems (Plate 6).

The wax pattern (Plate 7) shows the great amount of space available for slug movement in the vicinity of the tubers. A similar wax pattern made on a more sandy textured soil revealed little evidence of these subterranean cavities and the wax spread uniformly throughout the soil.

In some instances during these observations, disturbed slugs of the species A. reticulatus were seen to move into further cavities, and upwards to emerge on the soil surface alongside a plant stem (Plate 4). Whilst observations were in progress on a crop of Redskins in the early evening of the 2nd September (soil surface temperature = $5^{\circ}C$, humidity = 95%), numerous A. reticulatus were seen to emerge from crevices adjacent to plant stems and between soil clods on the ridge.

Plate 3 Cross sectional view of a ridge showing slugs near to tubers and slug damage to potato leaves - Redskin crop

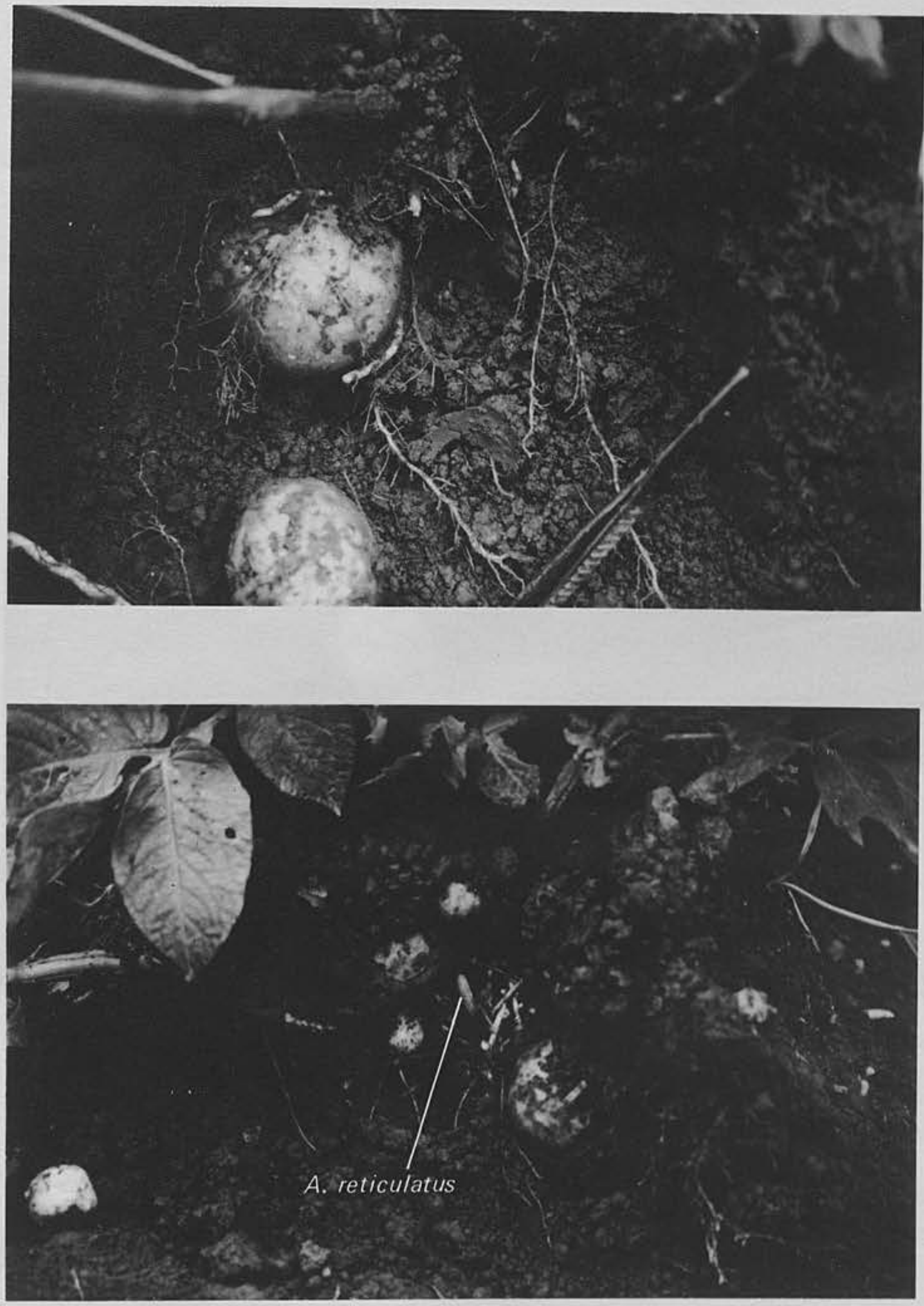


Plate 4 Cross sectional view of a ridge, showing numerous large cavities, earthworm burrows and casts adjacent to the tubers

Plate 5 Slugs of the species *A. reticulatus* 'resting' in earthworm burrows situated within the ridge of a potato crop

Plate 6 Aerial view of a potato plant of the variety Redskin showing leaf damage and the inter-soil clod spces adjacent to the plant stem

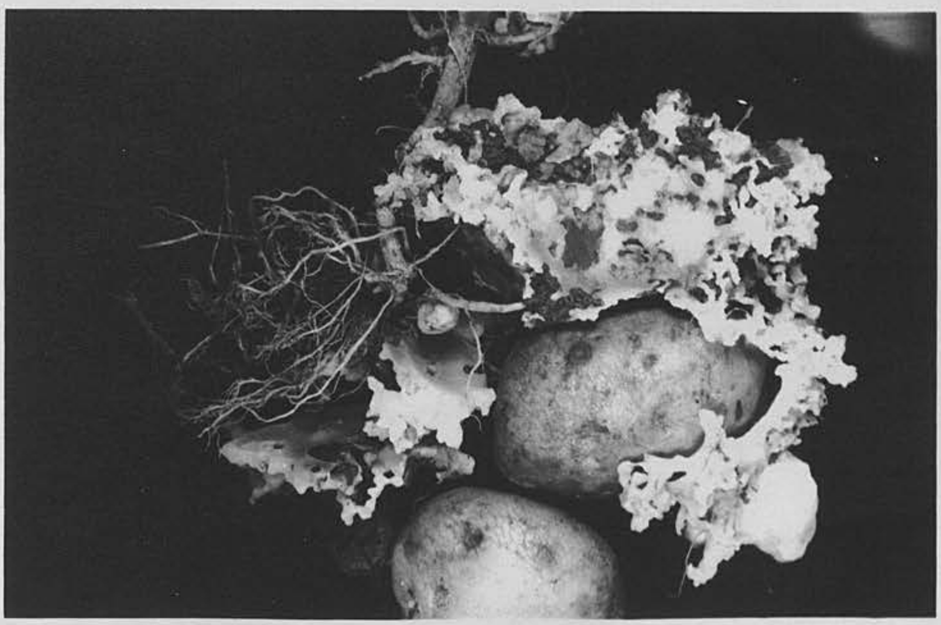


Plate 7 Wax pattern from the tubering zone of a potato plant showing the extent of the spaces available for slug movement

3) Self marking experiment

Three adult A. reticulatus found adjacent to the tubers of three of the six plants, were found to have been feeding on the dyed bran.

Discussion

There is ample evidence of the considerable amount of soil surface activity of the three slug species over the cropping period and even after the haulm has been destroyed, though there are species differences in the timing and frequencies of such activities. It appears that slugs do move into the ridge of some potato crops in midsummer and establish resting sites there, near to the tubers, and that they can cause small amounts of tuber damage at this early stage (Plate 8). Whether the irrigation of a crop forces slugs out of the very wet furrow and into the ridge is not clear. However, slugs were found frequently next to the tubers of non-irrigated crops in midsummer. This does not agree with the suggestions of some authors (notably Stephenson 1967) that slugs only move into the ridge after the wetting of the latter by the heavier and more prolonged autumn rains.

The environment around the tubers appeared to be very damp and rainfall would seep into these cavities via the soil-clod interstices and especially down the plant stems, providing an excellent, damp, protected refuge site for slugs from early July onwards.

It is suggested that slugs may be attracted to the rotting parent tuber, together with, or more possibly after earthworms, and that slugs may well utilise earthworm burrows considerably for underground movement. The wax patterns demonstrate that apart from any related differential in population density, that there is also less chance for slug movement in the ridge of crops grown on sandy soil where there are fewer stable soil 'clod' formations

Plate 8 Slug damage to leaves and immature tubers of a potato plant of the variety Redskin, examined in mid July

and earthworm burrows. The author has noticed that when heavy textured soils are cultivated in wet or moist soil conditions, before and after planting, that a very 'cloddy' soil structure is produced, which provides an ideal environment for slug survival and entry into the ridge.

The observation of the accumulated faecal deposits in the 'refuge' sites within the ridge and the evidence from the self marking experiment appears to support the existence of a 'homing' behaviour pattern in the activity of A. reticulatus (cp Newell 1966). A similar, longer range type of 'homing' behaviour has also been described for Helix pomatia by Edelstam and Palmer (1950).

The soil samples taken from the ridge and furrow of two crops (Section B, page 88) showed that even in late autumn, when slug damage is proceeding rapidly, that the percentage of slugs in the ridge and near to the tubers is not as high as would be expected if there was a mass movement from the furrow into the ridge. There was however very good evidence of an aggregation of A. reticulatus and A. hortensis near to the tubers within the ridge.

Crop husbandry and cultivation

i) Planting depth

A contingency 't' test was applied to the difference between the observed and expected values for damaged plants and tubers (Table 50). There were significantly more plants and tubers damaged at the 2" than 6" planting depth ($P > 0.5$ and $> P\ 0.01$ respectively).

Discussion

The reason for this apparent difference could be explained by the fact that more slugs may be able to locate those tubers nearer to the soil surface by way of the more numerous interstices at this level in the soil, i.e. slug activity was probably greater in the upper soil surface layers.

Table 50

Comparison of slug damage to the daughter tubers of setts planted at two depths

Planting Depth	6" Deep	2" Deep	Difference
1. Plants (Tuber hills)			
Damaged	7	18	11
Undamaged	45	32	13
	Chi squared value = 6.99 **		
2. Individual Tubers			
Damaged	11	50	40
Undamaged	536	604	68
	Chi squared value = 12.3 ***		

ii) Early versus late removal of haulm

Distribution of slugs on the plots

Analysis of slug counts in the soil samples (Table 51) shows that there were probably no significant differences in numbers either near to the tubers or in the furrow, between the treated and control plots in the latter part of the trial period.

Plant-tuber samples (Tables 1D - 5D incl. Appendix D)

Analysis of the data by a paired 't' test show that initially damage was equal on the treated and control plots and that only in the second and third samples were there any significant differences between the two.

In the second sample there was a significantly ($P > 0.5$) greater percentage of tubers and plants damaged on the treated plots, and though not significantly greater, twice as many slug holes on the treated than untreated plots. Conversely, in the third sample, there were significantly ($P > 0.5$) more damaged plants, but not tubers or holes, on the control plots. Fig. 8 shows that the destruction of the haulm made little difference to the soil moisture level in the ridge. In the dry periods, the ridge soil on both treated and control plots dried out more rapidly and to a greater extent than the furrow soil, and in the wet periods the furrow soil became only slightly wetter than the ridge soil.

Discussion

The early removal of haulm and weed vegetation did not appear to have any influence on the movement of the slug population, either from treated to untreated areas or vice versa or upon the extent of aggregation next to the tubers. Neither was there any substantial evidence of a greater amount of tuber

Table 51

Mean slug counts per sample unit from treated and untreated plots of the Haulm Removal Trial

Sample \ Species	Treated	Untreated	S.E. of Mean	Significance
1. Plant-soil sample				
A. reticulatus	0.41	0.35	0.03	NS
A. hortensis	0.55	0.47	0.05	NS
A. fasciatus	0.30	0.28	0.01	NS
Total	0.63	0.53	0.05	NS
2. Furrow sample				
A. reticulatus	0.32	0.33	0.02	NS
A. hortensis	0.41	0.37	0.04	NS
A. fasciatus	0.31	0.30	0.02	NS
Total	0.47	0.43	0.05	NS

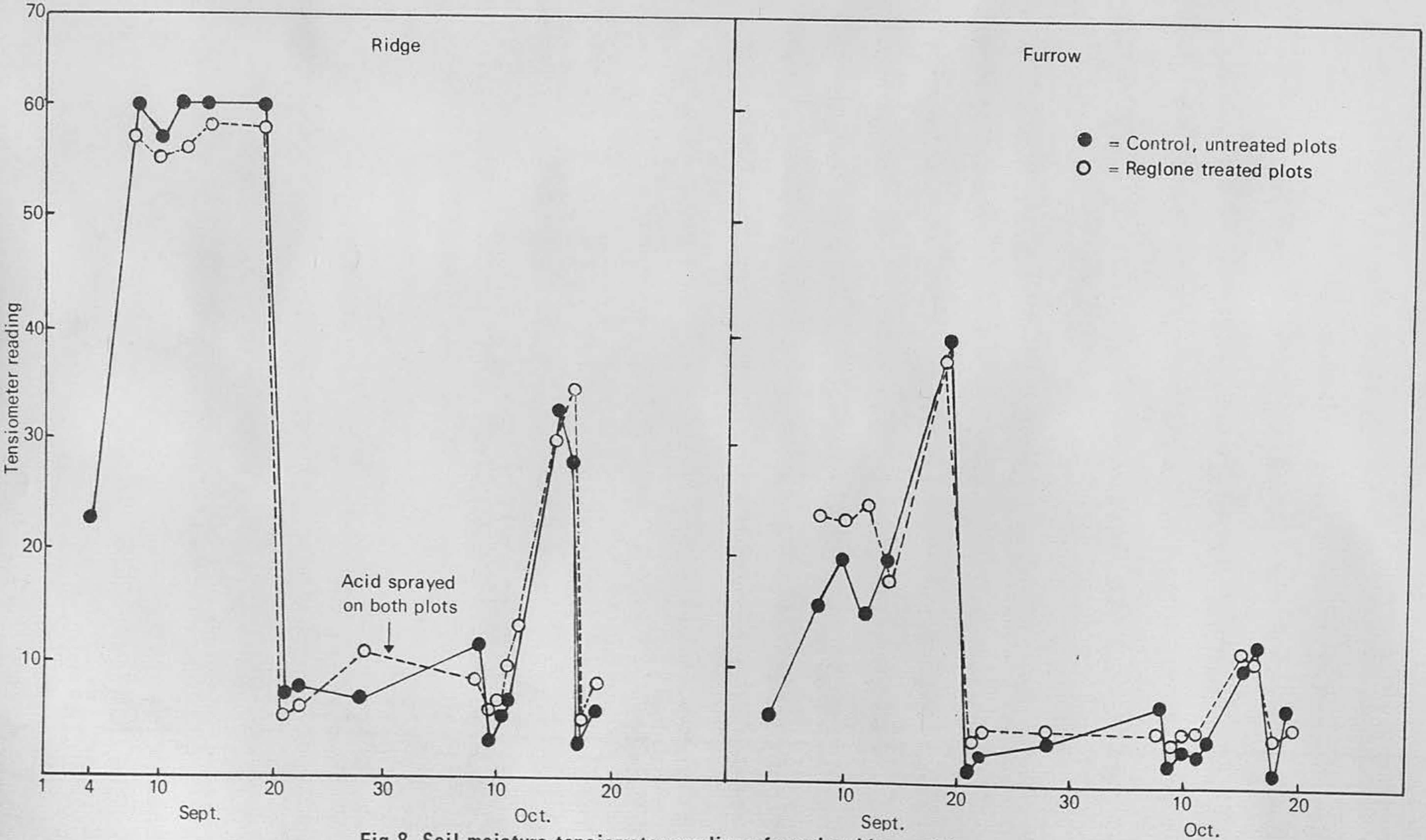


Fig 8 Soil moisture tensiometer readings from the ridge and furrow of treated and untreated plots – Haulm Removal trial (1967)

damage as a result of the earlier haulm destruction. It is unlikely that the premature haulm destruction on the control plots interrupted a trend of greater damage on the treated plots (second sample) since damage was slightly greater on the control plots immediately prior to this mishap.

The observations made on soil moisture over the trial period do not support the suggestion made by Stephenson (1967), namely, that water only becomes equally distributed throughout the ridge and furrow when the former is exposed to increases in rainfall, after the haulm has dried off. The data here shows that in September, the ridges on the treated and untreated areas became equally wetted after rain. It is suggested that from early August (at least) when there is full crop canopy, the heavier rain showers would wet the ridge soil to almost the same extent as the furrow, for variable periods of time. This does not conflict with the findings of Lacey (1962) whereby there is a tendency for water to be diverted towards the furrow when the amount of haulm is small. During full crop canopy a significant amount of water 'leakage' to the potato tubers probably takes place via the plant stems.

SECTION F

CONTROL OF SLUGS AND TUBER DAMAGE

Part 1 - Field Investigations

Introduction

To the author's knowledge there are no documented records of slug control measures carried out in the growing potato crop.

A series of field trials was carried out on susceptible crop varieties in which slug damage seemed likely to occur following a study of the slug populations present and other environmental factors.

The meta-bran slug bait pellet was chosen as the only commercially available molluscicide preparation suitable for application to the growing potato crop on a field scale. Metaldehyde sprays were not included since any immediate subsequent wet weather would greatly reduce their efficacy (persistence) and costly high volume spraying would be necessary in a full crop canopy. Additional runs through the growing crops with machinery were also undesirable from the husbandry aspect.

Materials and Methods

With the exception of the 1st and 2nd Trials the individual plot size used was 16 drills(36 ft)x 36 ft to provide:-

i) a large number of plants available for sampling (250 approximately)

ii) a large guard area of 3 drills width (6 ft) to curtail slug movement between plots, and

iii) conditions appropriate to pest control on a field scale.

The control and treated plots were randomised and all pellet applications were broadcast by hand at the rate of 28 lbs of formulation per acre. Each plant-tuber sample consisted of digging 10 plants per plot, either systematically or at random and an inspection of all tubers over 1.5 inches in diameter (approximately) made in situ before recovering the tubers. The amount of damage per sampled plant was thus determined.

1st Trial - Gullane 1966

A trial was carried out on a crop of Redskins after test pellet strips (in late June) had indicated high populations of *A. reticulatus* and *A. fasciatus*. The field was adjacent to one in which a previous Redskin crop had suffered heavy damage in 1965. A small plant sample taken in mid-July revealed slugs of both species next to the small tubers and some initial tuber damage (Plate 8).

Twelve plots, each 16 ridges wide by 50 yards in length, were marked out. Slug pellets of both the hard and soft type were applied (separately) on the following three dates:- 7th July, 27th July, 28th September to 6 plots.

Four tuber sample examinations were made on:-

1) 18th August,
2) 16th September,
3) 30th September and
4) 7th October.

Over the trial period further test pellet strips were put down in the furrow to assess the slug species composition, population size, surface activity and attraction to the pellets. The crop was ridged on 7th July, irrigated over a dry period of two weeks in mid-July and sprayed for blight on 18th July. By 3rd September the haulms were completely destroyed by blight. On the 25th August one soil moisture tensiometer was set up in the ridge, and one in the furrow position.

2nd Trial - Highfield, North Berwick (1966)

A small number of plant-tuber samples taken from a crop of K.Edwards on 21st September 1966, revealed considerable slug damage. Haphazard soil sampling, cover board trapping and test pellet strips indicated very high populations of A. reticulatus, A. hortensis and A. fasciatus. Five hundred and forty A. reticulatus were caught in one night (25th September) on one test pellet strip in a furrow length of 220 yards. Further high catches were made on more pellet strips from 26th September - 28th October.

Because the crop was not to be harvested until mid-October, an attempt was made at slug control in view of the great amount of slug activity on the soil surface, favouring control by surface baits.

Slug pellets of a 'soft' type were applied to the crop on 29th September, with a fertiliser drill. Four untreated control strips, 20 drills wide, were left at regular intervals across the field. At harvest, (19th-21st October) tuber samples were taken over a period of three days from 10 picking-collection boxes spaced equidistantly along the length of the drills. One hundred tubers were examined in each of 10 sample units from four treated and four untreated strips.

3rd Trial - Beanston (1967)

Very extensive leaf damage was noted in mid-August on a crop of Redskins that had been irrigated earlier in the month. A small plant-sample showed that $\frac{5}{10}$ plants with leaf damage had one or more slugs of the species A. reticulatus, A. hortensis and A. fasciatus adjacent to the tubers but that only one tuber had slug damage. Both the ridge and furrow soil was very damp as a result of the irrigation.

A kill of seventy adult A. reticulatus was obtained on a 30 yard long test pellet strip in a furrow on the night of 21st August. A further five, separate, 10 yard long test pellet strips produced only small kills of all three slug species because of very heavy rain following the placements.

In view of the apparently high slug population, active on the soil surface of the susceptible crop variety, a trial was set up to compare the effect of bait pellet applications to the crop when:-

(1) the haulms were green and slugs were actively feeding on them

with (2) later applications when the haulms were senescent(and slugs probably not feeding so actively on them).

A 36 plot trial consisting of 12 replicates of three treatments randomised in nine blocks was set up. The treatments were:-

(A) control - no pellets applied

(B) pellet applications on the 23rd August and the 7th September

(C) pellet applications on the 22nd and 28th September.

The haulm was burned down with acid on the 26th September and tuber-sample examinations were made on the 3rd and 11th October.

An analysis of the number of slugs on the three treatments was made from a plant-soil sample (8th October) and covered pellet traps (16th October) (see Section A, page 52).

<u>4th Trial - Beanston and Langhill 1967</u>

Because a successful reduction in tuber damage was obtained with meta-bran pellet applications in the growing crop at Gullane and because of the apparently greater success with the application earlier in the season, it was decided to obtain more detailed information on the optimum timing of applications. Two sites were chosen where slugs of the three species <u>A. reticulatus</u>

A. hortensis and A. fasciatus were found to be present in reasonable numbers by prior test pellet strips.

The relative efficacies of applying slug pellets on two Redskin crops at different times were investigated using the following treatment regimes -

(1) control - no pellets applied

(2) pellets applied in May only

(3) pellets applied in June only

(4) pellets applied in July only

(5) pellets applied in August only

(6) pellets applied in September only

(7) pellets applied in May and June

(8) pellets applied in May, June and July

(9) pellets applied in May, June, July and August

(10) pellets applied in May, June, July, August and September.

A 'hard' and 'soft' commercial brand of pellet were used separately at each site.

Six replicates of each treatment gave a 60 plot trial measuring 4320 sq.yds. This was such a large area that differences in slug population densities were quite likely to occur over the trial area. Therefore a balanced incomplete block design (see Fisher and Yates, 1953) comprising 15 blocks of four treatments was used to try and eliminate any such differential effects. An attempt was made to make all applications in mid-month during weather conditions favourable to slug surface activity. However, because of some prolonged dry, and wet weather periods, this was not always possible since slugs are relatively inactive on the soil surface in very dry conditions and very wet weather quickly reduces the efficacy of the pellets.

An attempt was made to assess the slug population in each plot of the Langhill Trial prior to pellet applications. Two biscuit tin lids, one with a halved potato tuber beneath, were positioned in two separate furrows (one furrow apart) in the centre of each plot on the 24th May and the response to the traps recorded over three nights. After the first application at one site (Langhill) in May, all the slugs visible on the soil surface over three days were collected and recorded, to assess the slug kill and the approximate population distribution.

Preliminary haphazard plant-tuber lifts were made in the guard rows of both sites in July and August to provide information on the progress of tuber damage. A full examination was not made until these initial sample tests indicated that sufficient tuber damage was in progress, for possible treatment differences to show. Two sample lifts were made at Beanston on the 29th-30th August and the 20th-21st September, unfortunately further examinations were not possible because of the unexpected early harvesting of the crop. Only one sample lift was made at Langhill, (4th October),where slug damage was light and again the crop was lifted earlier than expected.

In addition to the examination of tubers, records were made at one trial site (Beanston, first lift only) of damage to the leaves of the plants and the number of slugs found adjacent to the tubers.

Results and Discussion

1st Trial - Gullane 1966

Response to test pellet strips and pellet applications

The first test pellet strip (along 280 yards of furrow at one side of the trial area next to a grassy bank and hedge) gave a kill of 80 adult

A. reticulatus after one night (30th June). However, examination of the plots and test pellet strip for three weeks after the first pellet application (7th July) showed little evidence of any appreciable kill.

Three further test pellet strips (each 100 yards long), placed along separate furrows, adjacent to the trial, on 15th August, gave high kills of A. reticulatus and A. fasciatus from 16th August to 25th August (Table 1E, Appendix E). An inspection of the plots showed that the second pellet application (27th July) had given a considerable slug kill.

The addition of more pellets to the three test strips on 3rd September gave further high kills of both slug species over two nights though little visible kill was produced by the last pellet application to the treated plots (8th September).

Tuber damage

A preliminary examination of tubers in the guard rows of the plots on 12th July showed that slugs had commenced to damage tubers, measuring between ½" and 1½" in diameter, though the soil was relatively dry. Slugs of the two species A. reticulatus and A. fasciatus were seen adjacent to tubers.

Tables 52, 53 and Fig. 9 show the percentage of plants and tubers damaged in the four samples. There were significantly more damaged tubers on the treated than control plots on each sampling date. The damage on all plots increased at each sampling date with the exception of the last sample from the control plots. Only in the third sample was there a significant difference in the number of damaged plants between treatment and control though the control plots had a consistently higher number of damaged plants in each sample. Soil moisture tensiometer records at the 4" depth (Fig. 10) show that the ridge

Table 52

Slug damage in the control and treated plots - 1st trial Gullane, 1966

1) Plants with damaged tubers (Transformed data)

Sample - Treatment	Percentage of tubers damaged per plot replicate						Mean	Detransformed mean	Mean Reduction in damage by the treatment
	1	2	3	4	5	6			
Sample 1 18th August									
Control	50.8	26.6	45.0	50.8	56.8	50.8	46.8	53.2%	37%
							NS		
Treated	39.2	39.2	33.2	45.0	26.6	33.2	36.1	34.7%	
Sample 2 16th Sept.									
Control	63.4	50.8	85.0	50.8	71.6	71.6	65.5	82.8%	42%
							NS		
Treated	45.0	39.2	56.8	50.8	26.6	45.0	43.9	48.1%	
Sample 3 30th Sept.									
Control	85.0	50.8	85.0	63.4	85.0	63.4	72.1	90.6%	57%
							*		
Treated	26.6	39.2	39.2	26.6	39.2	63.4	39.1	39.1%	
Sample 4 7th Oct.									
Control	63.4	63.4	56.8	56.8	50.8	56.8	58.0	72.0%	28%
							NS		
Treated	50.8	56.8	39.2	50.8	63.4	26.6	47.9	55.0%	

Table 53

Slug damage in the control and treated plots - 1st trial Gullane, 1966

2) Tubers damaged (Transformed data)

Sample - Treatment	Percentage of tubers damaged per plot replicate						Mean	Detransformed mean	Mean Reduction in damage by the treatment
	1	2	3	4	5	6			
Sample 1 18th August									
Control	22.2	14.5	15.8	21.9	27.3	19.1	20.4	12.0%	38%
Treated	18.1	10.5	10.6	17.4	11.2	13.4	15.7 **	7.5%	
Sample 2 16th Sept.									
Control	28.0	22.0	25.2	20.5	26.7	20.6	23.4	15.5%	60%
Treated	15.3	17.4	15.1	17.3	7.0	17.2	14.9 ***	6.4%	
Sample 3 30th Sept.									
Control	37.7	35.1	29.0	26.6	32.6	28.4	31.5	27.4%	69%
Treated	13.5	22.8	15.3	11.5	16.4	21.1	16.7 **	8.4%	
Sample 4 7th Oct.									
Control	33.2	23.4	34.1	29.1	30.4	35.8	31.0	26.6%	57%
Treated	23.8	22.2	16.5	22.1	23.2	10.9	19.8 **	11.5%	

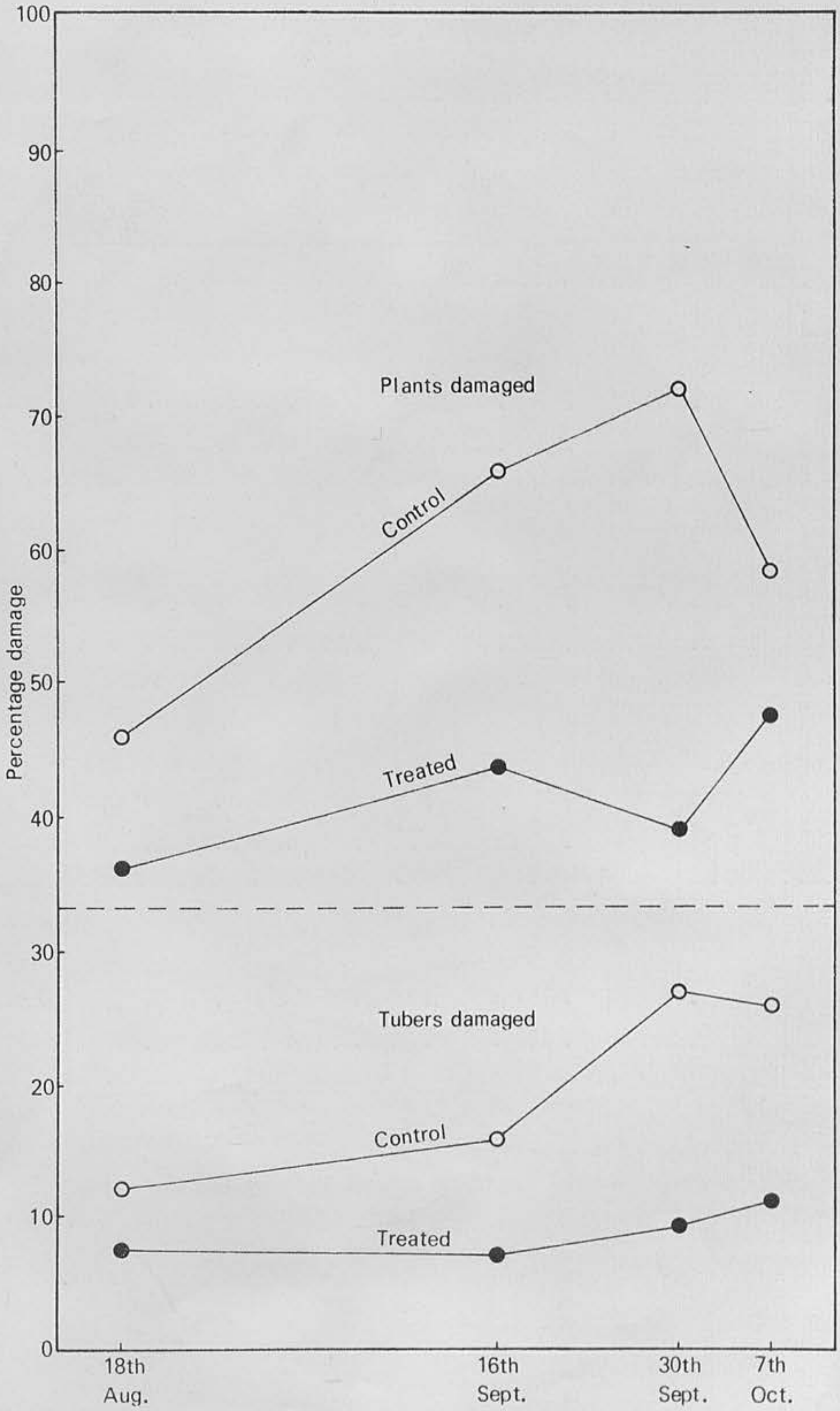


Fig 9 Plant and tuber damage – 1st trial Gullane (1966)

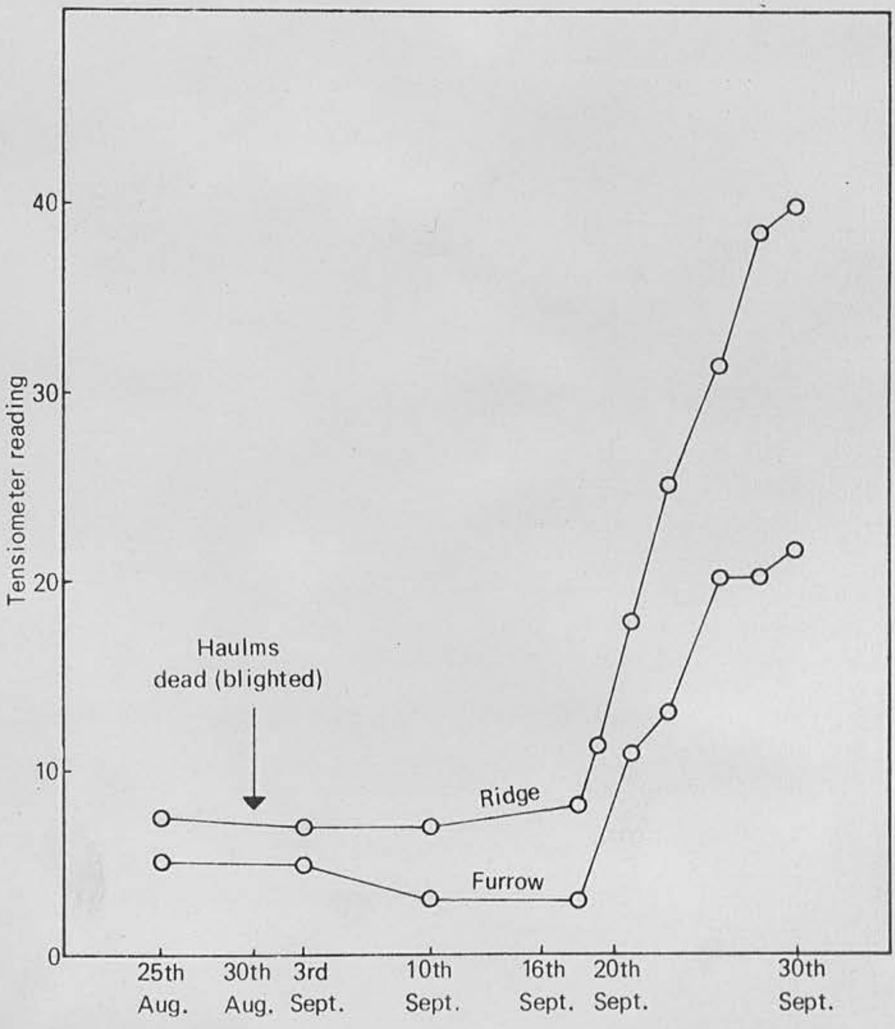


Fig 10 Soil moisture tensiometer readings - 1st trial, Gullane (1966)

soil was consistently drier than the furrow soil at this depth and that the former dried out more rapidly and to a greater extent over the period 16th September - 30th September. (A soil moisture curve was not constructed for this soil but one constructed for a similar soil at Bush, Fig. 2A, Appendix A, shows that readings of 10 and 40 on the tensiometer would indicate soil moistures of approximately 22% and 10% respectively.)

Discussion

There was a progressive increase in tuber damage over the sampling period (18th August- 7th October) on both the treated and untreated plots in spite of the dry soil conditions in the ridge between 16th - 30th September. As the percentage of damaged plants and tubers was always significantly higher on the untreated plots it is apparent that sufficient slugs were killed to significantly reduce damage. The response to the test pellet strips and field applications indicated that the second application (27th July) gave the best control of slugs. This was probably because of a high degree of slug activity on the soil surface as a result of the prolonged damp soil surface conditions caused by irrigation and rainfall.

The estimate of the average percentage of tubers damaged on the last two sampling dates showed a 63% reduction in damage on the treated plots (from 28% to 10%). This reduction is approximately equivalent to 30 cwts of total tubers in a 10 ton crop. Discarding a probable 10 cwts as seed and "chat" this represents a saving of approximately 1 ton of damage-free ware per 10 ton crop (1 acre yield). The cost of pellets for the three applications was £6.10.0d per acre plus approximately £1 per acre for labour costs. However, it was noted that only one application (27th July) gave any appreciable slug kill (at a cost of £2. 10. 0d.) The average value of one ton of Redskin ware is approximately £10 - £15, but as the amount of damaged ware that would probably be rejected was not estimated on this occasion, the exact benefit of the control measures could not be estimated.

2nd Trial - Highfield, 1966)

Dead A. reticulatus and A. fasciatus were not seen on the treated areas until after 7th October. The Mean percentage of damaged tubers and reject tubers (>3 holes per tuber) per plot is shown in Table 54. Though the variance is great, there would appear to be a greater amount of slug damage on the treated plots.

Discussion

This was not a properly replicated trial and all that can be inferred is that a late application of slug pellets did not appear to kill sufficient slugs to arrest slug damage at that stage of attack in the autumn. It was noted that few A. hortensis were killed by the pellets and this species may have been largely responsible for the continued attack on the tubers.

Table 54

Mean percentage of tubers damaged and reject tubers

2nd Trial - Highfield 1966

(Transformed data)

Plots \ Damage		% Tuber damage	% Tuber rejects
Treated	1	8.6	3.5
	2	8.1	2.3
	3	4.6	0.7
	4	8.1	3.7
Control			
Untreated	1	8.1	1.9
	2	7.1	3.8
	3	2.1	0.3
	4	2.1	0.3

3rd Trial - Beanston 1967

Estimation of the slug population on the trial area

The analysis of the soil sample and pellet trap counts has already been described in Section A (page 52). In brief, the counts showed that there were no significant differences in the slug population density (total of 3 species) between treatments in the period 8th - 16th October, but that the traps indicated greater surface activity on the untreated plots.

Tuber samples

The two samples were analysed, both separately and together as a combined sample. A comparison between lifts was also made (Table 55).

There was no significant difference in tuber damage between treatments either in the separate or combined analysis. There was a highly significant (P>0.01) increase in damage in the period (7 days) between the lifting of the two samples.

Discussion

Neither of the two pellet treatments were effective in controlling tuber damage. The pellet traps indicated less slug activity on the soil surface of the two treated plots, up to one month after application. However, the plant-soil samples showed no differences in slug numbers between treatments. This seems to indicate that the pellet applications were only successful in killing a proportion of slugs equally active on the surface of all treated plots, whilst the remaining population, less active on the surface, continued damaging the crop. Relatively few dead slugs of the species A. hortensis were seen, and it appears very likely that it was predominantly this species which survived the treatment and continued damaging the crop.

Table 55

Analysis of tuber damage - 3rd Trial at Beanston 1967

(Transformed data)

Treatment - Application / Sample - Damage	Control (A) Untreated	Treated (B) 23rd Aug. 7th Sept.	Treated (C) 22nd Sept. 28th Sept.	Significance	S.E. of Mean
Percentage of Plants Damaged					
Sample 1	41.8	37.8	35.4	NS	3.5
" 2	49.3	50.2	46.7	NS	3.5
Combined Sample	45.5	43.9	41.0	NS	2.5
Comparison between samples	-	-	-	***	3.2
Percentage of Tubers Damaged					
Sample 1	16.0	15.9	16.2	NS	1.50
" 2	21.5	21.4	20.3	NS	1.50
Combined Sample	18.7	18.7	18.2	NS	1.07
Comparison between samples	-	-	-	***	0.07
Slug Holes					
Sample 1	1.04	1.09	1.00	NS	0.08
" 2	1.24	1.20	1.19	NS	0.08
Combined Sample	1.14	1.14	1.10	NS	0.05
Comparison between samples	-	-	-	***	0.07

4th Trial - Site 1) Langhill

Response to preliminary test pellet strip and cover traps

The numbers and distribution of slugs caught by the cover traps from the 24th-25th May inclusive are shown in Fig. 11. Though the trap catch of each species, especially A. hortensis, was low, the distribution map shows a well defined area of distribution, with virtually no slugs on the eighteen, much sandier plots on the southern side of the trial area.

Response to the first pellet application in May

The numbers of adult slugs collected from the treated plots for three days after the pellet application in May are shown in the distribution maps (Fig. 12). The population distribution showed good agreement with the distribution pattern given by the cover trap counts. The eighteen sandy-soil plots on the southern side of the trial area supported a significantly smaller population of slugs than the remaining area and the densest populations of A. reticulatus and A. fasciatus were situated in the central plots on the eastern side of the trial area. The population of A. hortensis was very small and was apparently confined to a few plots in the central western edge of the trial area. The most dominant species appeared to be A. fasciatus.

Plant-tuber sample (Table 56)

1) Percentage of plants and tubers damaged

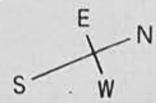
There was a significant difference between some treatments (P>0.5). Treatments 1 and 6 had a significantly higher number of damaged plants and tubers than treatments 3, 8, 9 and 10.

2) Slug holes

Tuber samples from treatment 1, 5 and 6 had significantly greater numbers of holes than treatments 3, 8, 9 and 10.

A. reticulatus

Plot rows \ Plot columns	1	2	3	4	5	6	7	8	9	10
6		1		2	6	3	2			1
5	1	4					2			
4	2	1		2	2	3	1			
3				1	1		2			
2		2	1				2			
1	1					3	1			



A. hortensis

Plot rows \ Plot columns	1	2	3	4	5	6	7	8	9	10
6										
5										
4										
3										
2									1	
1										

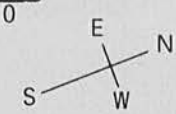
A. fasciatus

Plot rows \ Plot columns	1	2	3	4	5	6	7	8	9	10
6			1	1	3	1	2			
5				1						
4				1	2	1				
3			1		1	3				
2	1			1			2			
1										

Fig 11 Slug counts from cover traps on the 4th trial - Langhill (1967)

A. reticulatus

Plot rows \ Plot columns	1	2	3	4	5	6	7	8	9	10
6		22		31		44				16
5	4		29				11			1
4		12	16	14			7			
3					3		4			2
2	1		5		3	2	3		1	
1	1	3						7	3	



A. hortensis

Plot rows \ Plot columns	1	2	3	4	5	6	7	8	9	10
6										
5										
4								2		
3						2				
2						2	2			
1										

A fasciatus

Plot rows \ Plot columns	1	2	3	4	5	6	7	8	9	10
6		74		145		144				6
5	13		37				31	15		2
4		90	121	71			38	25		
3					86		40			9
2	35	50	78		78	69	44		14	
1	29	25					24	13	7	

Fig 12 Slug counts from the May pellet application - 4th trial Langhill (1967)

Table 56

Analysis of tuber damage - 4th Trial Langhill 1967

(Transformed data)

Timing of Applications	% of Tubers damaged	% of Damaged plants	Slug holes
1. Control	10.3	26.9	0.72
2. May	6.0	14.7	0.45
3. June	3.6	8.6	0.22
4. July	6.6	14.9	0.47
5. August	7.3	18.6	0.72
6. September	11.3	25.0	0.81
7. May, June	4.7	10.9	0.32
8. May, June, July	1.1	3.5	0.08
9. May, June, July, August	2.3	6.9	0.12
10. May, June, July, August, September	3.1	5.9	0.20
S.E. of Mean	2.0	4.8	0.15
Significance	*	*	*

Discussion

The slug kill given by the application in May confirmed the results of the cover trap counts, namely that the distribution of slugs was not uniform over the trial area, and that the choice of a balanced incomplete block design was indeed very necessary for such a large scale trial. The response to the cover trap was very low and indicated more A. reticulatus than A.fasciatus, though the kill from the pellet application in May suggested the opposite. It is realised of course that, to a large extent, these figures are only a reflection of surface activity and not total populations. However, it seems reasonable to assume that because of the ideal weather conditions favouring slug surface activity over the three days, that the majority of slugs would have been active on the surface.

The highest plot kill of 150 A. fasciatus and 47 A. reticulatus represents surface active populations of 5×10^3 and 1.6×10^3 respectively, per acre of the crop. These are very low adult populations (see page 25 Section A) even in comparison with the populations recorded in the following late Autumn (25.3×10^3 A. fasciatus, 42.7×10^3 A. hortensis and 52.3×10^3 A.reticulatus), on the plots of the variety trial which were situated in another more clayey area of the same field. Seasonal differences may have been largely responsible for this population difference.

The very slight tuber damage was to a large degree a reflection of these low slug populations. However, the analysis showed that tuber damage was reduced by certain treatments. The best control was obtained by applying pellets in (1) June only, (2) May and June, (3) May, June and July, (4) May, June, July and August, (5) May, June, July, August and September. The counts of slug holes showed that pellet applications in September (and to a lesser extent August) gave no control, as recorded in the previous trials. The application in June appeared to have contributed most to the control in the more successful permutations of the application schedule.

It must be stated that because of the difficulties of applying the pellets in comparable weather conditions in each month, that the results from this site and the following site may largely be a reflection of localised short-term weather conditions prevailing at the time of application and may therefore in fact give little comparison between the months in which applications were made.

Site 2) Beanston

Preliminary test pellet strip counts

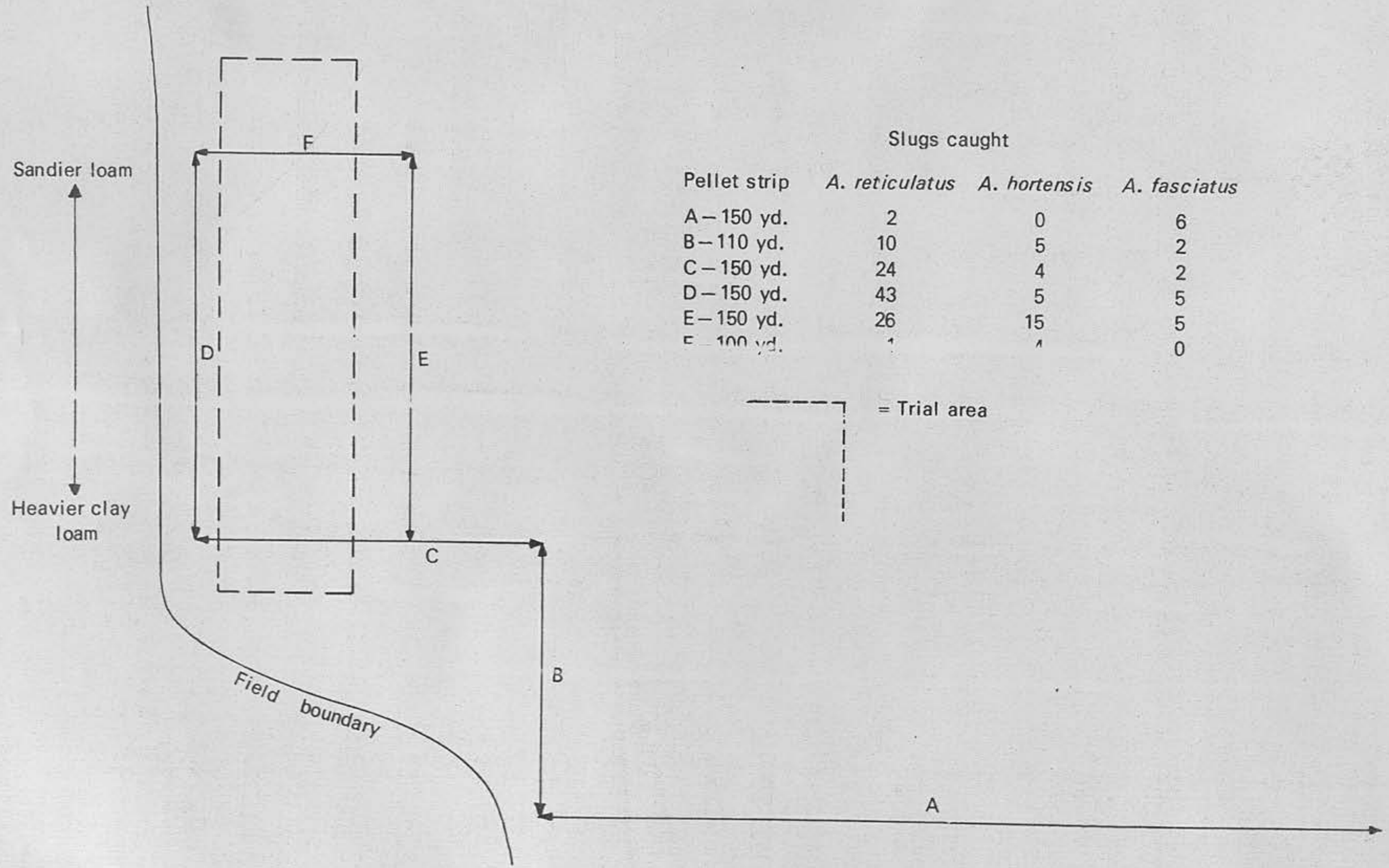
Slug counts from the four strips on the trial area are shown in the diagram of the trial area (Fig. 13). The three species *A. reticulatus*, *A. hortensis* and *A. fasciatus* were present in the area. The poisoned slugs were not easy to locate on the heavier clay soil at this site since it had been cultivated in wet conditions, leaving a coarse cloddy texture,which afforded a greater number of refuge sites, readily available to the slugs. A lower count on the sandier loam region of the trial area was apparent.

Plant-tuber samples

The results of the two sample lifts are presented in the following paragraphs both as two separate and one combined sample (Tables 57, 58).

Percentage of tubers damaged

There was no significant difference between treatments in the first sample though tuber damage in treatments 3, 7, 8, 9 and 10 was considerably lower than in treatments 1, 2, 4 and 6.



Slugs caught

Pellet strip	*A. reticulatus*	*A. hortensis*	*A. fasciatus*
A – 150 yd.	2	0	6
B – 110 yd.	10	5	2
C – 150 yd.	24	4	2
D – 150 yd.	43	5	5
E – 150 yd.	26	15	5
F – 100 yd.	1	4	0

Fig 13 Slug counts from test pellet strips on the 4th trial site Beanston

Table 57

Analysis of tuber damage and slug counts from the first plant sample 4th Trial Beanston 1967

(Transformed data)

Slug species - Damage factor / Treatment regime	A.reticulatus	A.hortensis	A.reticulatus A.hortensis A.fasciatus	% of Plants with Damaged tubers	% of Tubers Damaged	Slug Holes	% of Plants with Damaged Leaves
1.Control (untreated	1.17	0.95	1.31	25.8	10.34	0.49	56.8
2.May	0.94	0.91	1.09	27.8	10.9	0.82	66.0
3.June	0.98	0.81	1.05	16.9	5.5	0.33	47.0
4.July	1.24	1.29	1.63	26.4	12.1	0.79	63.6
5.August	1.40	1.10	1.66	21.1	8.8	0.56	59.7
6.September	1.57	1.17	1.94	37.9	15.1	0.92	60.6
7.May, June	0.97	0.91	1.23	12.4	5.4	0.37	34.0
8.May, June, July	0.89	0.77	0.97	15.8	5.8	0.35	41.0
9.May, June, July, August	1.04	0.73	1.13	17.4	7.3	0.34	31.8
10.May, June, July, August, Sept.	0.87	0.77	0.88	13.1	5.5	0.23	31.0
S.E. of Mean	0.18	0.11	0.19	5.6	2.4	0.13	6.2
Significance	NS	*	*	NS	NS	**	***

Table 58

Analysis of tuber damage in the second plant sample and the combined sample (1+2)

4th Trial Beanston 1967

(Transformed data)

Sample - Damage factor / Treatment - Regime	Sample 2			Combined Sample 1 + 2		
	% of Plants Damaged	% of Tubers Damaged	Slug Holes	% of Plants Damaged	% of Tubers Damaged	Slug Holes
1. Control (untreated)	32.5	13.7	0.86	46.0	18.5	1.00
2. May	31.7	19.7	0.91	45.7	23.7	1.18
3. June	32.2	14.7	0.83	40.4	15.8	0.90
4. July	30.4	11.9	0.67	42.1	17.6	1.00
5. August	29.6	10.3	0.84	47.3	15.3	1.09
6. September	35.8	14.6	0.96	64.3	21.5	1.22
7. May, June	22.3	11.2	0.62	29.6	13.4	0.75
8. May, June, July	18.5	6.1	0.48	25.9	8.9	0.60
9. May, June, July, August	36.2	14.1	0.76	43.5	16.3	0.83
10. May, June, July, August, Sept.	31.1	11.8	0.70	36.6	13.5	0.79
S.E. of Mean	4.6	2.2	0.14	6.5	2.6	0.13
Significance	NS	**	NS	*	*	NS

In the second sample, damage in treatment 8 was significantly lower than in all other treatments except number 10. The combined analysis of the two samples showed that treatments 7, 8, and 10 had significantly ($P>0.5$) less damage than treatments 1, 2 and 6.

Slug holes

Significant differences between treatments were present only in the first sample in which the tubers from treatments 3, 7, 8, 9 and 10 had fewer slug holes than 2, 4 and 6. In the second sample, treatment 8 had the least number of holes. The combined analysis showed no significant difference between the treatments; though the tubers in treatments 3, 7, 8, 9 and 10 had the smallest numbers of holes.

Percentage of plants with damaged tubers

In neither sample were there any significant differences between treatments, though in the first sample the values for treatments 3, 7, 8, 9 and 10 were considerably lower than the others. In the second sample, treatment 8 had by far the lowest value. The combined analysis showed no significant difference between treatments, but again treatments 7 and 8 had considerably fewer damaged plants.

Percentage of plants with leaf damage

Treatments 3, 7, 8, 9 and 10 had a very significantly higher ($P>0.01$) proportion of plants with leaf damage than treatments 1, 2, 4, 5 and 6.

Adult slugs found next to tuber samples

There was a significantly larger number of total slugs of the three species found near to the examined tubers in treatments 4, 5 and 6 than in 8 and 10. There was no significant difference in the numbers of adult *A. reticulatus* between treatments, though treatments 4, 5 and 6 had the most and 8 and 10 the least. There were significantly higher numbers of adult A. hortensis in treatments 5 and 6 than in 3, 8, 9 and 10.

Discussion

The results of the two separate samples appear to show certain anomalies. This was most probably because of the wide variation occurring within treatments. On the second sampling date, the amount of slug damage was greater than on the first and the differences between treatments had largely disappeared, with the exception that the sample from treatment 8, the applications in May, June and July, showed considerably less damage.

Assuming the measurement of the number of slug holes to be the best assessment of slug-damage activity, and looking closely at trends within and between samples, it is apparent that treatments 3 and 8, the application of pellets in June only and in May, June, and July gave the best control of slug damage. This again shows agreement with the more successful early applications in the previous trials. The apparently poor control given by the application in September is also in agreement. However, both of the crops in the 4th Trial were harvested relatively early and there was thus little chance for these late applications to have an effect.

The amount of slug damage to the potato leaves also shows good agreement with the degree of damage to the tubers in the different treatments. This indicates that the pellet applications killed slugs of those species feeding on the haulms as well as the tubers and that to some extent, leaf damage can probably be used as a guide to tuber damage.

Part 2 - Small scale laboratory and field investigations

Introduction

In an attempt to utilise a cheaper chemical as a contact poison with some residual action, tests were carried out with dilute solutions of formaldehyde.

Tests were also conducted on the contact effect of two granular preparations, one based on Fuller's earth containing 4% 'Sevin' (1 Napthyl-N-methylcarbamate) an insecticide and 4% metaldehyde; and one based on maize cob chips, containing 10% 'Temik' /2 Methyl-2-(methylthio)proprionaldehyde O-(methylcarbamoyl)oxime/ a highly active carbamate known to possess molluscicidal properties (Crowell 1967). The action of 'Temik' as a plant-systemic molluscicide was investigated since the successful use of a compound for killing slugs by this mode of action would appear to be unique.

Materials and Methods

All laboratory tests were carried out on soil at a temperature of $20^{\circ}C \pm 2^{\circ}C$ in shallow, 2" deep tins, 0.5 sq. ft. in area, each containing an inch depth of damp soil. Slug mortality was defined by failure to respond (contract) to a simple touch stimulus. In one test some slugs were recorded as being moribund but not dead.

Formaldehyde Sprays

(a) Range finding test

Two pilot tests were conducted to establish the speed of action and residual effects of 1%, 2%, 3%, 4% and 5% solution strengths, based on the commercial formalin solution (40% formaldehyde + 60% water). The solutions were applied from a hand sprayer in a timed application of one second onto four adult slugs of the species A. reticulatus in each container. This application was sufficient to visibly 'wet' the soil surface and the slugs.

The times taken to give total mortality of the slugs in each treatment were recorded and a second batch of slugs put in to the containers after one hour with a similar subsequent observation.

(b) Replicated test

Tests were carried out against the four slug species A. reticulatus, A. hortensis, A. fasciatus and M. budapestensis. There were four replicates of each species, each consisting of five adult slugs per container. Timed one-second applications of four formaldehyde solution concentrations (1%, 2%, 3% and 4%) were made and the containers covered with glass sheets after spraying. Slug mortalities were assessed after 24 hours.

(c) Application in the field

A small field test with the 2% and 4% spray dilutions was carried out on two furrows of a potato crop at 10 p.m. on the 14th October 1966 when numerous A. reticulatus and A. fasciatus were active on the soil surface. A thermohygrograph, situated in the furrow indicated a temperature of 4.5°C and 95% humidity. The potato haulm had been burned off three weeks previously.

The two concentrations were applied by knapsack sprayer along two adjacent 200 yard furrow lengths, using 1.5 gallons of each dilution strength. The spray nozzle was kept at a height of 12" above the bottom of the furrow and the solutions applied at a slow walking pace to give a 100% soil surface cover.

The two furrows were inspected on the following morning at 9 a.m. and all dead and moribund slugs removed. Final mortalities were recorded after allowing three days recovery at 5°C.

Metaldehyde-'Sevin' granules

Laboratory tests involving three methods of application were carried out with eight adult A. reticulatus per container and four replicates per method. 0.5 grams of granules per container were used in each treatment (equivalent to 50 lb per acre - the manufacturers recommended rate). The three methods of application were:-

1) Granules spread on the soil surface

2) Granules distributed in two equal heaps on the surface

3) Granules mixed evenly throughout the soil.

The containers were sealed with perforated lids and kept at a laboratory temperature range of 20°C ± 4°C. The containers were inspected daily for eight days and any dead slugs recorded and removed. A second identical test was carried out at a lower temperature of 10°C in controlled temperature cabinets.

'Temik' granules

a) Contact effect

i) One 'granule' was placed on the dorsal surface of 10 adult slugs of the three species A. reticulatus, A. hortensis and A. fasciatus which were kept in petri dishes at a temperature of 10°C.

ii) 0.25 grams of the compound were spread evenly over the surface of a one inch depth of soil and three adult slugs of the three species placed on the soil surface (not in contact with any of the granules). Five replicates were set up. The containers were kept at a temperature of 10°C and inspected at intervals over 48 hours. At the end of 48 hours the slugs were removed, carefully washed and placed in a damp box to observe any subsequent recovery.

b) Systemic effect

i) Lettuce plants grown in solution

A 1% and 0.25% by weight (active material) solution of 'Temik' were made up in 10 ml of distilled water in two test tubes. A young lettuce seedling (four leaf stage) was positioned in the top of each tube with the roots immersed in the solution. The cultures were kept at 10°C and leaves removed after three and four days for feeding tests. A second batch of plants was set up in the same solutions after a period of two weeks and leaves removed for feeding tests after two days.

Each test consisted of presenting one leaf (approximately 20 sq.cm) to two slugs of each of the species A. reticulatus, A. hortensis, A fasciatus and M. budapestensis housed on damp filter paper in a petri dish. Mortalities were recorded daily for six days.

ii) Application to the roots of lettuce plants

Four grams of the granules were applied to the peat surface in a seed tray (97 sq. ins.) containing ten young lettuce plants. The granules were watered into the peat and the tray kept at 10°C. Leaves were removed after 2, 3, 4 and 8 days for feeding tests with A. reticulatus (five or ten slugs per test) in the manner previously described.

iii) Application to turf

Granules were sprinkled on the surface of two grass turves (12.5 sq.ins) at the dosage rate of 15 lb per acre of active material. Light overhead watering was given for three days to release the toxicant. The turves, enclosed by a 4" high aluminium grid, were housed in shallow trays containing water (Fig.14).

Perforated plastic mesh was placed over the turf to allow growth of grass through the mesh whilst preventing slugs from coming into contact with the granules. Five A. reticulatus were housed in each cage for four days at

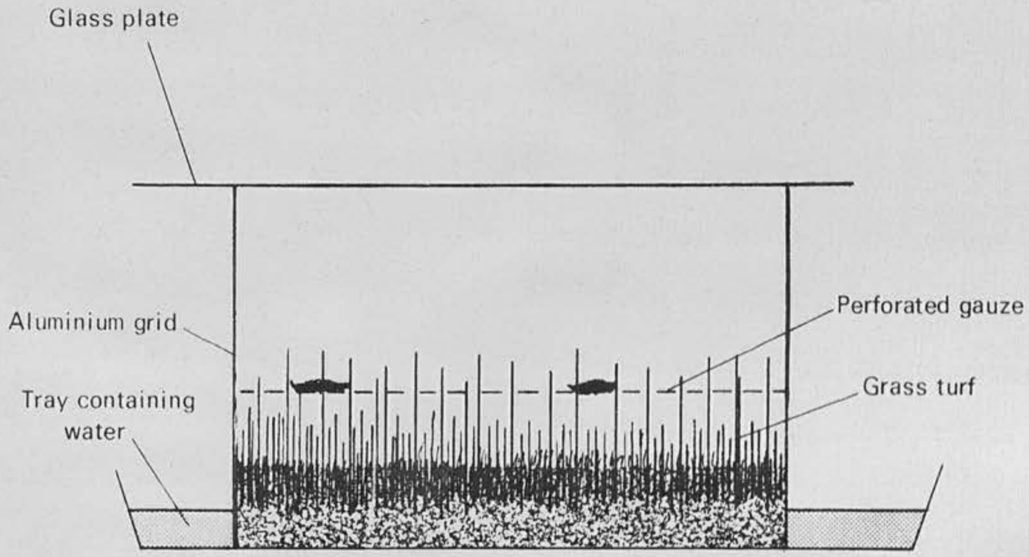


Fig 14 Method of housing slugs on treated turf

$10^{\circ}C$, three days after applying the granules. Mortalities were assessed daily for four days.

In each of these three tests, Controls consisting of untreated plants and turf were used.

Results and Discussion

Formaldehyde sprays

a) Range finding test

The times taken to produce total mortality were:-

Spray concentration	Initial exposure	Exposure after 1 hour
1%	12 minutes	1 hour 40 minutes
2%	10 "	1 " 20 "
3%	6 "	1 " 10 "
4%	4 "	40 "
5%	3 "	30 "

In view of the marginal extra efficacy of the 5% solution, it was omitted from further tests.

b) Replicated test

Table 59 shows the number of slugs killed out of a total of 20 per species. The greater efficacy of the 2% than the 1% solution was noticeable and an almost complete kill was obtained with the 4% solution. Probit analysis of the results (Table 60) showed that the estimated LD_{50} and LD_{90}'s for each slug species were very similar; approximately 1.8% and 3.7% by volume solution concentrations respectively.

c) Application in the field

None of the collected slugs recovered and the numbers of adult slugs killed by the two spray applications over a length of 200 yards of furrow were:-

Table 59

Counts of dead and moribund slugs after spraying with 4 formaldehyde solution strengths and allowing 24 hours recovery

Slug Species		Solution Concentrations 1%	2%	3%	4%	Control No Formaldehyde
A.reticulatus	R_1	2	3	3	5	0/5
	R_2	0	2	3	4	
	R_3	0	5	4	5	
	R_4	1	2	4	5	
Total		3	12	14	19	
A.hortensis	R_1	1	2	4	5	0/5
	R_2	1	4	3	4	
	R_3	0	3	5	5	
	R_4	1	5	4	4	
Total		3	14	16	18	
A.fasciatus	R_1	0	3	4	5	0/5
	R_2	1	4	5	5	
	R_3	0	3	3	4	
	R_4	0	4	4	4	
Total		1	14	16	18	
M.budapestensis	R_1	0	3	4	5	0/5
	R_2	0	4	4	5	
	R_3	2	4	5	5	
	R_4	1	1	3	4	
Total		3	12	16	19	

Table 60

Calculated lethal doses of formaldehyde contact sprays applied to 4 slug species (Probit analysis)

Slug species	Doses in % concentration by volume of formaldehyde			
	LD_{50}	fiducial intervals at the 95% level	LD_{90}	fiducial intervals at the 95% level
A. reticulatus	1.8	1.4 - 2.2	3.9	3.1 - 6.3
A. hortensis	1.7	1.3 - 2.1	3.7	2.9 - 5.9
A fasciatus	1.9	1.5 - 2.2	3.5	2.9 - 5.0
M. budapestensis	1.8	1.3 - 2.2	3.6	2.8 - 5.7

	2% solution	4% solution
A. reticulatus	218 = 1 per yard	368 = 2 per yard
A. fasciatus	185 = 1 per yard	142 = 0.8 per yard
A. hortensis	2	1
Total	405 = 2 per yard	511 = 2.5 per yard

There were no visible effects on other soil fauna.

Discussion

The susceptibilities of the four slug species to the very rapid contact action of the spray applications were very similar, which is of vital use for field control. The short field test confirmed the usefulness of this contact spray molluscicide. It was not known however, to what extent any residual formaldehyde deposits on the soil surface killed or affected slugs which emerged on to the soil surface after spraying. Those slugs hit directly by the field spray were immediately immobilised with the exudation of much slime. The numbers of slugs killed by the direct action compared very favourably with one night kills by test pellet strips on the same and other crops.

The rate of application used on the field test was equivalent to 73 gal. per acre. The cost of 73 gal. of 4% and 2% formalin solutions is approximately £2 and £1 respectively. (10 gal. of commercial 40% solution costs approximately £3. The cost would probably be less if bought in greater bulk).

Metaldehyde-'Sevin' granules

Table 61 shows the daily mortalities and the total mortality recorded for the eight day period at the two test temperatures. At the higher tempera-

Table 61

Total slug kills by metaldehyde/'Sevin' granules in 4 replicates of 8 slugs per treatment

Application - treatment	Spread on soil surface		2 small heaps on soil surface		Mixed with soil		Control No Granules	
Test temperature	15-20°C	10°C	15-20°C	10°C	15-20°C	10°C	15-20°C	10°C
Examination								
After 24 hrs	1	0	10	0	3	0	0	0
48 "	4	0	14	0	5	0	1	0
72 "	13	0	16	2	9	0	2	0
96 "	13	0	17	3	9	5	2	0
120 "	14	2	20	6	10	8	2	0
144 "	16	4	20	6	10	9	2	0
168 "	19	4	22	7	10	9	4	0

ture, there were equally high mortalities on the surface and 'mixed-in' applications though death was more rapid in the former treatment. There was a significant mortality in the controls and the response to the heaped application appeared to be significantly lower than the other two treatments.

The lethal effect at the lower temperature was far less and the kill with the heaped application was slightly higher than the surface treatment. However, the overall kill was so small that little distinction could be made between the treatments.

Discussion

The markedly higher response at the higher temperature range indicated a significant temperature-treatment interaction. Greater slug movement was apparent at the higher temperature, which would increase the chance of contact with granules. Whether or not there is an increased physiological toxicity effect at a higher temperature is not known. This higher temperature is unlikely to occur at the soil surface level at night in this region and even a temperature of 10°C is rather high. The response to the 'heaped' applications indicated active attraction to the granules and dissection showed that a few slugs had eaten granules.

'Temik' granules

a) Contact effect (i)

All ten slugs of the species A. reticulatus and A. hortensis were moribund (muscularly relaxed) ten minutes after treatment, and all were dead after fifteen minutes. Slugs of the species A. fasciatus died after thirty minutes.

Contact effect (ii)

All slugs in each replicate were moribund after 48 hours and no slug had moved more than one inch away from its original position. After 144 hours in the 'recovery' container all fifteen A. reticulatus and six of the fifteen A. hortensis were dead, whilst the remaining slugs of this species and all of the A. fasciatus were still moribund and appeared unlikely to recover since they were apparently not able to feed on the lettuce leaves provided.

b) Systemic effect

i) Lettuce plants grown in solution

The slugs of each species fed on the treated leaves in all of the tests. There was no lethal effect produced by the 2 day treatment with the 1% solution (Table 62). A 100% kill of the A. reticulatus and M.budapestensis was given by the 3 and 4 day old treated leaves with both the freshly prepared 1% and 0.25% solutions and the 2 week old 1% solution. 50% of both the two Arion species died after feeding on the lettuce grown in the freshly prepared 1% solution. One of the five A. reticulatus and both of the M. budapestensis died after feeding on the leaves grown in the 2 week old 0.25% solution.

ii) Application to the roots of lettuce plants

Mortality after 6 days

Leaves cut after:-	2 days	4 days	5 days	8 days	Control
Leaf stage i) First or second leaf	0/5	1/5 (+ 4 affected)	1/5 (+ 3 affected)	0/10 (+ 7 affected)	0/10
ii) Youngest leaf	-	-	-	1/10	0/10

Slugs that had fed on the leaves after 4, 5 and 8 days showed clear symptoms of poisoning though only a small percentage were killed. After 8 days

Table 62

The feeding to slugs of lettuce plants grown in a solution of 'Temik'

Species \ leaves cut after	Final Mortalities after 6 days (5 slugs per test)							
	1% w solution				0.25% w solution			
	2 days	3 days	4 days	Control	2 days	3 days	4 days	Control
a) Fresh solution								
A.reticulatus	0	5	5	0	0	5	5	0
A.hortensis	0	2	2	0	0	0	0	0
A.fasciatus	0	2	3	0	0	0	0	0
M.budapestensis	0	5	5	0	0	5	5	0
b) 2 week old solution								
A.reticulatus	-	5	-	0	-	2	-	0
A.hortensis	-	0	-	0	-	0	-	0
A.fasciatus	-	0	-	0	-	0	-	0
M.budapestenis	-	5	-	0	-	5	-	0

one slug was killed after feeding on a very young leaf.

iii) Application to turf

Mortality after 4 days (5 slugs)

Replicates:-	1	2	Control
	5 dead	5 dead	0

All slugs in each replicate were quickly poisoned and died after feeding on the treated turf in the first two days of exposure.

Discussion

The results suggest that sufficient quantities of the toxicant were taken up into the lettuce and grass plants via the roots to provide a lethal oral dose to slugs feeding on them. The very high concentrations of 1% and 0.25% solutions were however rapidly phytotoxic and not a practical field proposition. The dose of 55 lb/acre active material used here in test ii) is also very high though dosages of 15 lb/acre active material (test iii) have been used in potato root eelworm trials.

A difference in species susceptibility was noted. The species A. reticulatus and M. budapestensis were apparently far more susceptible than the two Arion species which recovered after ingesting equal amounts of leaf. An initial poisoning effect was however produced with the characteristic signs of carbamate poisoning (extended body, copious watery mucous on the skin, drooping tentacles, i.e. general loss of muscle tone).

General Discussion on control of tuber damage

The slug pellet trials showed that applications of molluscicide baits to the growing crop can control a certain amount of damage. The timing of these applications is important and the early summer treatments appeared to be the most effective, late applications after August being too late to effect any marked degree of control. There is a certain amount of specificity involved in the use of metaldehyde baits and a high kill of A. hortensis seems unlikely.

Apart from the seasonal aspects of application, the immediate local weather conditions are of great importance in determining the efficiency of control measures. The prior use of 'test' pellet strips have shown to help considerably in determining suitable times for application. Observations on the use of 'hard' and 'soft' types of pellets indicated that the former are the most likely to give a higher kill because of their greater persistence in periods of heavy rain and drought. Slugs appear equally capable of feeding on hard or soft pellets and since very little feeding is necessary to ingest a lethal dose (0.06 mg, Cragg and Vincent, 1952) a soft type of pellet is unnecessary. It is suggested that a very much smaller, hard type of weather resistant pellet would supply a sufficiently large feeding substrate whilst giving a far better ground distribution in the crop; which is of great importance with an expensive product. A preparation with a far greater persistency is necessary for the more successful and economic agricultural use of surface baits.

Ideally slug control should be carried out before planting either (1) in the previous autumn, when the majority of the slugs are active on or near the soil surface of stubble and grass fields or (2) in the early spring, during the cultivations immediately prior to planting. Where sampling indicates high populations, more thorough control measures can be effected, such as (i) contact sprays of formaldehyde,applied at night during periods of high surface activity; (ii) application of a systemic and contact molluscicide such as 'Temik', where the highly toxic chemical can then be ploughed in after application with little risk of harmful effects to mammalian or avian wild life.

The recent invention of E. Ramon (Weed Research Organisation) whereby chemicals for the control of 'couch grass' are sprayed into a suspension of soil in air, provided by an unguarded rotovator may prove to be a useful way of applying molluscicidal sprays and powder or granular preparations into the top soil layer for more effective slug control by a more prolonged contact effect.

Economic aspects of control measures in the potato crop

For a control measure to be of use the cost of such a measure must be less than the price of the extra yield minus the harvesting cost of this extra yield, dressing out costs and other variable costs such as haulage.

The cost of two bait pellet dressings at the 28 lb/acre rate would be £4 plus labour costs; a total cost of approximately £5 per acre. Therefore one would need to obtain an increased saleable ware yield of about one third ton per acre (at an average price of £15 per ton) in order to cover costs.

A study of the tuber damage (washed tubers) on two of the variety susceptibility trials (Table 63) showed that at one site (Langhill), pellet control applications would probably have been marginally profitable on the crop of K.Pink with losses on the K.Edward and G. Wonder. At the other site

(Gateside) control measures on the crops of Redskin, K.Edward and G.Wonder would have been far more profitable, with a loss on the K.Pink. This assumes that in both cases a reduction of tuber damage in the order of 50-60% could have been obtained as in the first trial at Gullane and price payments made as shown in Table 40 page 129.

However it is not possible to gain the full advantage of a damage free crop unless quality payments are made. The smaller amount of dressing-out-labour required with a damage free crop is of course another valuable cost benefit.

Table 63

The likely profitability of hypothetical bait-pellet control measures on the 4 susceptible potato varieties at two of the variety trial sites, assuming a 50% reduction in reject ware tuber damage

	Weight of ware saved per 10 ton crop (Approx. 1 acre yield)		Profit and Loss per 10 ton crop (1 acre yield) after deducting £5 per acre for Control Measures	
Site / Potato Variety	Langhill	Gateside	Langhill	Gateside
Redskin	3.8 cwt	10 cwt	0	Profit £2.5s.0 - £7.5s.0.
K.Pink	5.0 cwt	2.5 cwt	Marginal	Loss of £2 - £3.
K.Edward	2.5 cwt	10 cwt	Loss of £2 - £3.	Profit of £2.5s.0 -£7.5s.0.
G.Wonder	0.15 cwt	5 cwt	Loss of £5.	Profit of £4 - £7.5s.0.

REFERENCES

ANSCOMBE, F.J. (1948). The transformation of Poisson, binomial and negative binomial data. Biometrika, 35, 246 - 254.

BAKER, C.B.M. and WAINES, R.A. (1957). Wireworm and slug damage to ware potatoes, 1954-56. Plant Pathology, 6 : (4), 115 - 122.

BARNES, H.F. and WEIL, J.W. (1942). Baiting slugs using metaldehyde mixed with various substances. Ann. appl. Biol., 29, 56 - 68.

BARNES, H.F. (1944). Discussion on slugs. I. Introduction, seasonal activity of slugs. Ann. appl. Biol., 31, 160 - 163.

BARNES, H.F. and WEIL, J.W. (1944). Slugs in gardens: their numbers, activities and distribution. Part 1. J.Anim. Ecol., 13, 140 - 175.

BARNES, H.F. and WEIL, J.W. (1945). Slugs in gardens: Part 2. J. Anim. Ecol., 14, 71 - 105.

BARNES, H.F. and STOKES, B.M. (1951). Marking and breeding *Testacella* slugs. Ann. appl. Biol., 38, (2), 540 - 545.

BARNES, H.F. (1953). The absence of slugs in a garden and an experiment in re-stocking. Proc. Zool. Soc. Lond., 123, 49 - 58.

BATTE, E.G. and SWANSON, L.E. (1952). Laboratory evaluation of organic compounds as molluscicides. J. Parasitology, 38, 65 - 68.

BETT, J.A. (1960). The breeding seasons of slugs in gardens. Proc. Zool. Soc. Lond., 135, 559 - 568.

BLACKMAN, G.E. (1942). Statistical and ecological studies in the distribution of species in plant communities. I. Dispersion as a factor in the study of changes in plant populations. Ann. Bot. N.S., 6, 351 - 370.

BLISS, C.I. and FISHER, R.A. (1953). Fitting the negative binomial distribution to biological data and note on the effective fitting of the negative binomial. Biometrics, 9, 176 - 200.

BLISS, C.I. and OWEN, A.R.G. (1958). Negative binomial distributions with a common k. Biometrika, 45, 37 - 58.

BRUEL, W.E., and MOENS, R. (1958). Remarques sur les facteurs écologiques influencant l'efficacite de la lutte contre les Limaces. Parasitica, 14, 135 - 148.

BURTON, W.G. (1965). The sugar balance in some British potato varieties during storage. Part I) Preliminary observations. European Potato Journal, 8, 80 - 91.

CAMERON, A.E. (1939). The control of potato slugs. J. Min. Agric., 46, 454 - 462.

CARRICK, R. (1936). Investigation into the biology and habits of slugs attacking the potato crop. Report - Dept. of Agric. Zool., Edinburgh University.

CARRICK, R. (1938). The life history and development of Agriolimax agrestis L., the grey field slug. Trans. Roy. Soc. Edin., 59, 563 - 597.

CRAGG, J.B. and VINCENT, M.H. (1952). The action of metaldehyde on the slug Agriolimax reticulatus (Müller). Ann. appl. Biol., 39, 396 - 406.

CROWELL, H.H. (1967). Slug and snail control with experimental baits. J. Econ. Entomology, 60 (4), 1048 - 1050.

DAINTON, B.H. (1943). Effect of air currents, light, humidity and temperature on slugs. Nature, 151, 25.

DAINTON, B.H. (1954). The activity of slugs. I. The induction of activity by changing temperatures. J. Exp. Biol., 31, 165 - 187.

DAINTON, B.H. (1954). The activity of slugs. 2. The effect of light and air currents. J. Exp. Biol., 31, 188 - 197.

DUTHOIT, C.M. (1961). Assessing the activity of the field slug in cereals. Plant Pathology, 10, 165.

DUTHOIT, C.M.G. (1963). Slug activity and feeding potential. A.R.C. 825/63.

EDELSTAM, C. and PALMER, C. (1950). Homing behaviour in gastropods. Oikos 2 (2), 259 - 270.

EDWARDS, C.A. and HEATH, G.W. (1964). The Principles of Agricultural Entomology. London. Chapman and Hall Ltd.

EL-NAGDY, G.E.D.A. (1962). The Mechanism of infection of potatoes by Oospora pustalans causing skin spot. Ph.D. Thesis. Edinburgh University.

ESSLEMONT, J.M. (1938). Observations on the control of potato slugs. Scot. J. Agric. 21, 147 - 152.

FINNEY, D.J. (1946). Field sampling for the estimation of wireworm populations. Biometrics, 2 (1), 1 - 7.

FISHER, R.A. and YATES, F. (1953). Statistical tables for biological, agricultural and medical research. Oliver and Boyd, Edinburgh.

GETZIN, L.W. (1965). Control of the grey garden slug with bait formulations of a carbamate molluscicide. J. Econ. Entomol., 58 (1), 158 - 9.

GETZIN, L.W. and COLE, S.G. (1964). Evaluation of potential molluscicides for slug control. Washington Agr. Exp. Sta. Bull., 658, 9p.

GIMMINGHAM, C.T. and NEWTON, H.C.F. (1937). A poison bait for slugs. J. Min. Agric., 44, 242 - 246.

GOULD, H.J. (1961). Observations on slug damage to winter wheat in East Anglia, 1957 - 1959. Plant Pathology, 10, 142-146.

GOULD, H.J. (1962). Tests with seed dressings to control grain hollowing of winter wheat by slugs. Plant Pathology, 11, 147 - 152.

GOULD, H.J. (1965). Observations on the susceptibility of main crop potato varieties to slug damage. Plant Pathology, 14, (3), 109 - 111.

HADDEN, N.G. (1936). Gardening Illustrated. May 2nd. p 255.

HODSON, W.E.H. (1924). Preliminary experiments on slug control. J.R. Hort. Soc., 49, (2), 191 - 196.

HODSON, W.E.H. (1925). Some further notes on the control of slugs. J. R. Hort. Soc., 50, 257 - 9.

HOWITT, A.J. (1961). Chemical control of slugs in orchard grass - Ladino white clover in the Pacific Northwest. J. econ. Ent., 54, 778 - 781.

HUNTER, G.W., FREYTAG, R.E. and RITCHIE, L.S. (1952). Potential molluscicides screened in the laboratory. J. Parasit., 38, 509 - 516.

HUNTER, P.J. (1966). The distribution and abundance of slugs on an arable plot in Northumberland. J. Anim. Ecol., 35, 543 - 557.

HUNTER, P.J. (1967). The effects of cultivations on slugs of arable land. Plant Pathology, 16, 153 - 156.

HUNTER, P.J. (1968a). Studies on slugs of arable ground. l. Sampling methods. Malacologia, 6 (3), 369 - 377.

HUNTER, P.J. (1968b). Studies on slugs of arable ground. ll. Life cycles. Malacologia, 6 (3), 379 - 389.

JONES, T.P. (1965). The effect of Aldrin on yield and slug damage to ware potatoes. Plant Pathology, 14, (1), 39 - 40.

LACEY, J. (1962). The activity of Phytophthera infestans (Mont) De Bary in soil. Ph.D. Thesis. Reading University.

LANGE, W.H. Jnr. and MACLEOD, G.F. (1941). Metaldehyde and caseinate in slug and snail baits. J. Econ. Entomology, 34, 321 - 322.

LAUGHLIN, R. (1965). Capacity for increase; a useful population statistic. J. Anim. Ecol. 34, 77 - 93.

MILES, H.W., WOOD, J. and THOMAS, I. (1931). On the ecology and control of slugs. Ann. appl. Biol., 18, 370 - 400.

MILNE, A. (1959). The centric systemic area-sample treated as a random sample. Biometrics, 15, 270 - 297.

MORETON, B.D. (1953). Preliminary experiments with metaldehyde suspensions and slugs. Plant Pathology, 2, 49 - 51.

NEWELL, P.F. (1965). The behaviour and distribution of slugs. Ph.D. Thesis. London University.

RAW, F. (1951). The ecology of the garden chafer, Phyllopertha horticola (L) with preliminary observations on control measures. Bull. Ent. Res., 42, 605.

RUPPEL, R.F. (1959). Effectiveness of Sevin against the grey garden slug. J. Econ. Entom., 52, 360.

SALT, G. and HOLLICK, F.S.J. (1944). Studies of wireworm populations. I. A census of wireworms in pasture. Ann. appl. Biol., 31, 52.

SOUTH, A. (1964). Estimation of slug populations. Ann. appl. Biol., 53, 251 - 259.

SOUTH, A. (1965). Biology and ecology of Agriolimax reticulatus (Müll.) and other slugs: spatial distribution. J. Anim. Ecol. 34, 403 - 419.

SOUTHWOOD, T.R.E. (1966). Ecological Methods. Methuen Press.

STEPHENSON, J.W. (1959). Aldrin controlling slug and wireworm damage to potatoes. Plant Pathology, 8, 53 - 54.

STEPHENSON, J.W. (1964). Rep. Rothamsted Exp. Sta., 1964, 148 p.

STEPHENSON, J.W. (1967). The distribution of slugs in a potato crop. J. Applied Ecology, 4, (1), 129.

STEPHENSON, J.W. (1965). The effects of irrigation on damage to potato tubers by slugs. Europ. Potato J., 8, 145 - 149.

THOMAS, D.C. (1944). Field sampling for slugs. Ann. appl. Biol., 31, 163 - 164.

THOMAS, D.C. (1947). Some observations on damage to potatoes by slugs. Ann. appl. Biol., 34, 246 - 251.

THOMAS, D.C. (1948). The use of metaldehyde against slugs. Ann. appl. Biol., 35, 207 - 227.

TROUGHT, T.E.T. and HEATH, E.D. (1963). A new approach to the control and assessment of slug damage. A.R.C. 12/64.

WAIN, R.L. (1963). New herbicides with molluscicidal activity. Nature, 200, No. 4901, 28.

WEBLEY, D. (1962). Experiments with slug baits in South Wales. Ann. appl. Biol., 50, 129 - 136.

WEBLEY, D. (1963). Experiments with slug baits in 1959. Plant Pathology, 12, 19 - 20.

WEBLEY, D. (1964). Slug activity in relation to weather. Ann. appl. Biol., 53, 407 - 414.

WEBLEY, D. (1965). Aspects of trapping slugs with metaldehyde and bran. Ann. appl. Biol., 56 (1).

APPENDIX A

SOIL SAMPLING

1) Sample size

Initially a turf soil sample unit measuring 1 sq.ft. in area by 4" deep was taken from each of the sixteen grass sub-plots at Bush using a steel sampling grid and the samples progressively flooded to expel the slugs. However, these large sample units were found to be too bulky for easy handling and transportation and a large amount of space and large volumes of water were involved. They were thus regarded as being too large for practical field use.

After this first routine monthly sample, taken in January 1967, monthly soil sample units measuring 9" x 8" x 4" deep (0.5 sq.ft.) were taken, from March 1967 - July 1968. In some cases two units were dug to give an 8" deep sample. Each unit was fitted into a 5" deep biscuit tin and covered with the tin lid. This sample unit had the advantage of being easily handled and transported and could be stored for short periods of time before inspection, if desired. The sampling holes on the plot were refilled immediately after with turf units taken from the surrounding guard areas.

Although the numbers of slugs recovered from the 0.5 sq.ft. sample units were not always large and zero values were often recorded, they were comparable with numbers recovered from 1 sq.ft. samples taken by both South and Hunter. The standard errors of the mean estimates were found to equal and in some cases were better than the estimates of previous workers and thus the sample size was taken to be sufficient for the practical estimation of slug populations.

2) Method of sampling on arable land

Soil samples were taken from a ploughed field and the ridge and furrow of potato crops using the same apparatus in the manner described above (Plate 2), with the slight modification of removing soil from one side of the sample grid to facilitate the intact removal of the more friable soil. Samples were dug when soil conditions were reasonably dry as compaction problems were encountered when taking wet soil samples. A sample unit taken from the ridge which included a potato plant (+ tubers) was termed a 'plant-soil' sample unit. A sample taken from the ridge in-between two potato plants was termed an 'interplant-soil' sample unit, and a sample from the furrow, a 'furrow-soil' sample unit.

3) Sampling stations

In all cases, except from the three potato variety trials, the '16 plot' Haulm-Removal Experiment and the Late pellet application trial, the sampling station was chosen by pacing out two random co-ordinate numbers in each of the sub-plots of the investigational area and sampling at the point of intersection. On the other sites, samples were taken from systematically chosen positions within the individual plots.

4) Recovery of slugs from turf and soil samples

The vegetation of each turf sample was removed down to the soil level. The vegetation was carefully searched during this process and any slugs and eggs transferred to damp petri dishes. The vegetation from each unit was placed in a double Kraft paper soil-sample-bag, weighed and then washed on a bank of sieves to recover any remaining slugs and eggs.

The first turf sample from Bush was progressively flooded in plastic bowls (see Hunter 1966) both by the addition of water to the dustbin reservoirs by hand and via a number of rubber tubes connected to a central water reservoir. However, this method was found to be unsatisfactory both from the recovery time involved (5-6 days) and the difficulty of operation. Subsequent samples were progressively flooded within the watertight biscuit tins. The slugs were flooded out of the samples by adding amounts of water over the soil surface (usually 200 ml) at intervals, such that the water level was raised by ½" at minimum intervals of four hours. The initial amounts of water added depended largely on the soil moisture content of the sample but was usually between 200 and 400 ml.

The less stable arable soil samples were flooded in larger containers (16" x 16" x 9" deep), in which there was a maximum soil depth of 2", thus minimising the likelihood of slugs being trapped by soil compaction. Samples containing potato tubers were flooded after the removal and inspection of the tubers.

After March 1967 slugs were successfully extracted from all turf-soil samples by subjecting the sample units to a progressive heat treatment. The sealed tins were placed in a large galvanised tray, measuring 5' x 3' x 7" deep, containing water an inch deep at a temperature of 25°C. The temperature of the water was raised approximately 3°C every thirty minutes over a period of four to six hours, and the temperature held at approximately 50°C until all slugs had been forced on to the sample surface. It was generally found that earthworms were the first to appear, at a soil surface temperature of between 25°C and 30°C and that slugs appeared soon after, at a surface temperature of between 35°C and 45°C. By regular inspection of the samples in the last hour or two of the procedure, slugs were removed before suffering any apparent heat damage and thus were suitable for weight records.

Sometimes turf samples were slightly wetted and left in a relatively warm room prior to extraction in order to induce slugs to the surface of the sample.

The top layer (vegetative-root - soil surface) of each routine turf-soil sample was washed through with a water jet whilst holding the sample (in tin), with the soil surface vertical, over a bank of sieves. Almost all the slug eggs were removed from the grass plot samples by this procedure.

The recovery efficiencies of the flooding and heat treatment methods were checked at intervals by washing batches of soil samples through a bank of three 12" diameter sieves (sizes $\frac{3}{8}$", $\frac{1}{8}$" and $\frac{1}{32}$") immediately after treatment, and picking off any remaining slugs and eggs from the bottom sieve. When there was much residue on the bottom sieve, the slugs were floated off in magnesium sulphate.

In some cases when many arable soil sample units had been taken the slugs and eggs were extracted by the direct washing method from some units whilst other units were flooded; in order to recover slugs from the sample as quickly as possible.

The efficiency of the standard soil-washing method was checked by introducing a known number (unknown to the operator) of slugs of all sizes of the three species and their eggs into a small number of soil samples and subjecting the samples to the standard method used.

Table 1A

Recovery of a known number of slugs and eggs from 10 soil sample units by the standard soil washing method

Species :-	A. reticulatus			A. hortensis			A. fasciatus		
Age :-	Adult	Young	Eggs	Adult	Young	Eggs	Adult	Young	Eggs
Introduced	50	20	200	37	5	100	21	4	50
Recovered	50	19	192	37	5	65	21	4	49
% Recovery	100	95	96	100	100	65	100	100	98

Adult = >25 mg

Young = <25 mg

Numbers of slugs recovered from 11 progressively flooded routine monthly turf samples, with check washes of 6 samples and corresponding percentage recoveries

Table 2A

A. reticulatus

Recovery Stage	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
Vegetative Layer	74	52	60	38	49	50	30	60	95	18	40
Flooded out	21	20	9	13	19	18	18	12	50	90	20
Soil wash check	1	-	1	-	-	1	-	0	3	-	0
Total	96	72	70	51	68	69	48	72	148	108	60
% recovery	99		99			99			98		100

Mean percentage recovery from 6 samples - 99%

Table 3A

A. hortensis

Recovery Stage	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
Vegetative Layer	36	24	38	9	3	24	11	29	61	1	17
Flooded out	61	50	14	39	5	29	15	22	92	43	8
Soil wash check	4	-	2	-	-	1	-	2	5	-	0
Total	101	76	54	48	8	54	27	53	156	44	25
% recovery	96		96			98		98	97		100

Mean percentage recovery from 6 samples = 97%

Table 4A

A. fasciatus

Recovery Stage	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
Vegetative Layer	20	17	20	7	3	5	4	16	20	0	8
Flooded out	17	9	3	9	6	4	6	4	21	12	7
Soil wash check	1	-	0	-	-	1	-	1	0	-	0
Total	38	26	23	16	9	10	10	21	41	12	15
% recovery	98		100			90		96	100		100

Mean percentage recovery from 6 samples = 98%

Table 5A

Numbers of slugs recovered by the progressive flooding of arable soil samples from 4 potato crops with check washes and percentage recoveries

Recovery Stage :-	Flooded			Check Wash			Percentage Recovery		
Species / Site - sample	R	H	F	R	H	F	R	H	F
Beanston									
Variety trial - plant-soil sample	14	29	3	0	0	0	100	100	100
Langhill									
Variety trial - plant-soil sample	40	8	19	3	2	4	93	80	83
Gateside - Variety trial									
Plant-soil sample 1	65	135	22	3	6	2	96	96	92
Plant-soil sample 2	52	82	24	3	5	2	95	94	92
Furrow sample	9	22	11	2	0	3	82	100	79
Interplant sample	0	9	3	0	0	1	-	100	75
Beanston 1) Haulm removal trial									
i) Furrow	4	12	3	0	0	0	100	100	100
ii) Plant-soil	10	31	1	0	0	0	100	100	100
iii) Interplant	2	4	1	0	0	0	100	100	100
2) Covered pellet trap soil sample	16	45	6	0	2	0	100	96	100
3) Late pellet application trial - Plant-soil sample	9	60	1	0	0	0	100	100	100
4) Covered pellet trap plant-soil sample	3	36	5	0	0	0	100	100	100
Overall Recovery	225	486	99	11	15	12	96	97	89

Numbers of slugs recovered from progressively heated samples

1) Routine monthly turf samples from Bush

Table 6A

A. reticulatus

Recovery Stage	Feb.	March	April	May	June	July
Vegetative Layer	58	52	44	54	28	71
Heat Treatment	23	15	6	6	6	104
Check Wash	1	1	1	0	0	0
Total	82	68	51	60	34	178
% Recovery	99	99	98	100	100	98

Mean Percentage Recovery from 5 samples = 99%

Table 7A

A. hortensis

Recovery Stage	Feb.	March	April	May	June	July
Vegetative Layer	7	20	25	24	12	2
Heat Treatment	9	16	12	12	9	16
Check Wash	2	1	1	0	0	0
Total	18	37	38	36	21	18
% Recovery	89	98	98	100	100	100

Mean Percentage Recovery from 6 samples = 98%

Numbers of slugs recovered from progressively heated samples

1) Routine monthly turf samples from Bush

Table 8A

A. fasciatus

Recovery Stage	Feb.	March	April	May	June	July
Vegetative Layer	6	11	7	20	8	5
Heat Treatment	6	1	10	6	4	3
Check Wash	1	0	2	0	0	0
Total	13	12	19	26	12	8
% Recovery	91	100	90	100	100	100

Mean Percentage Recovery from 6 samples = 97%

2) Turf sample from the grass paddock - Beanston

Table 9A

Species / Recovery Stage	A. reticulatus	A. intermedius
Vegetative Layer	20	68
Heat Treatment	5	9
Check Wash	0	5
Total	25	87
% Recovery	100	94

Numbers of slugs recovered from progressively heated samples

3) Arable sample from ploughed stubble - Beanston

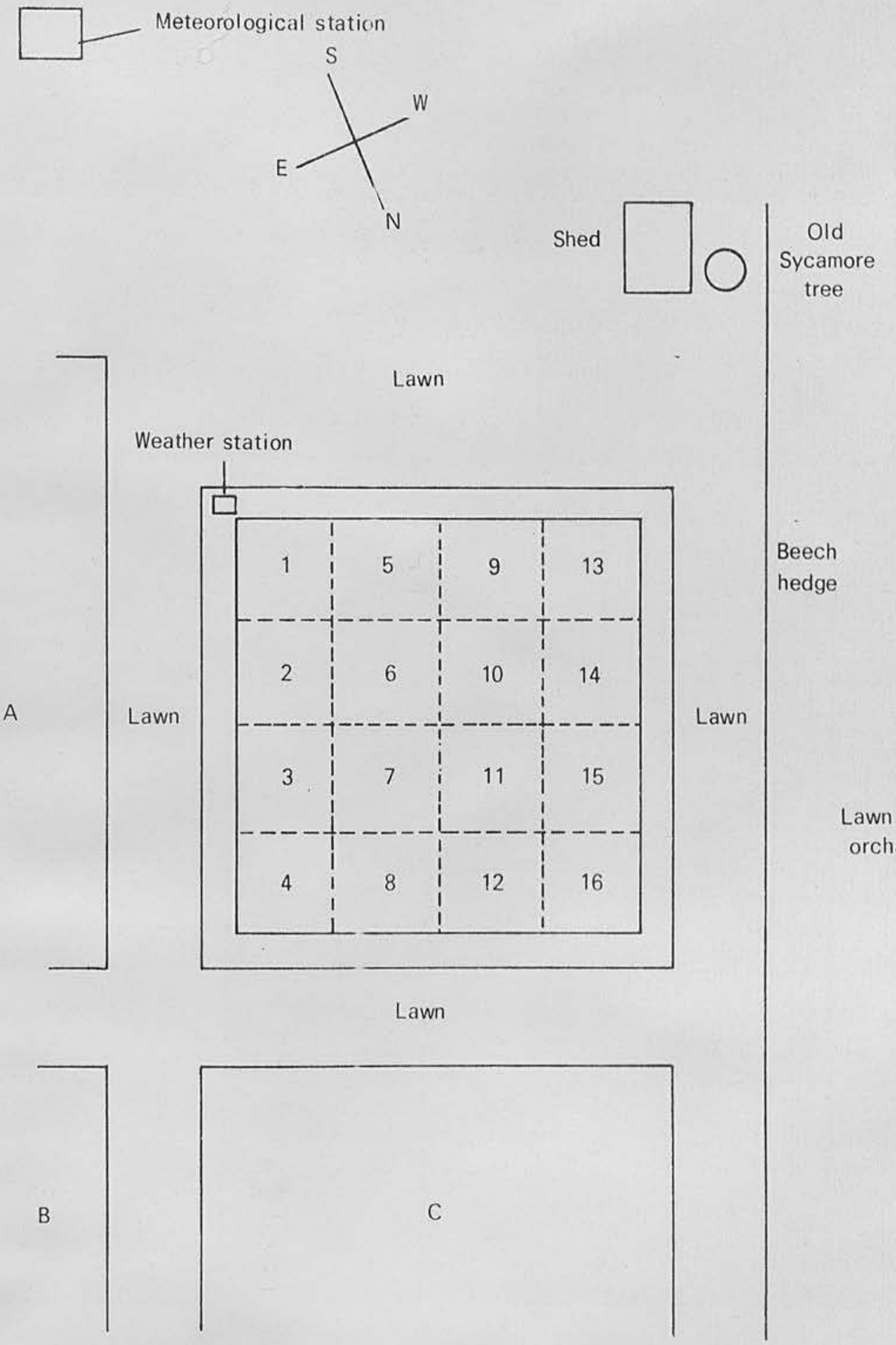
Table 10A

Species / Recovery stage	A. reticulatus	A. hortensis	A. fasciatus
Heat Treatment	34	24	3
Check Wash	3	7	1
Total	37	31	4
% Recovery	92	78	75

Table 11A

A comparison of the percentage sample recovery efficiencies obtained by different Authors

Species	A.reticulatus	A.hortensis	A.fasciatus	A.intermedius
A) Flooded Samples				
i) Turf				
Author: South	99	-	94	81
Hunter	92	88	-	-
Warley	99	97	98	-
ii) Arable				
Author: South	94	-	80	50
Warley	96	89	97	-
B) Heated Samples				
i) Turf				
Author: Warley	99	98	97	94
ii) Arable				
Author: Warley	92	78	75	-



A,B,C — Arable plots under rotational cropping

Scale ½" – 10 ft.

Fig 1A Plan of the permanent grass plot at Bush (divided into 16 sub plots) and the immediate vicinity

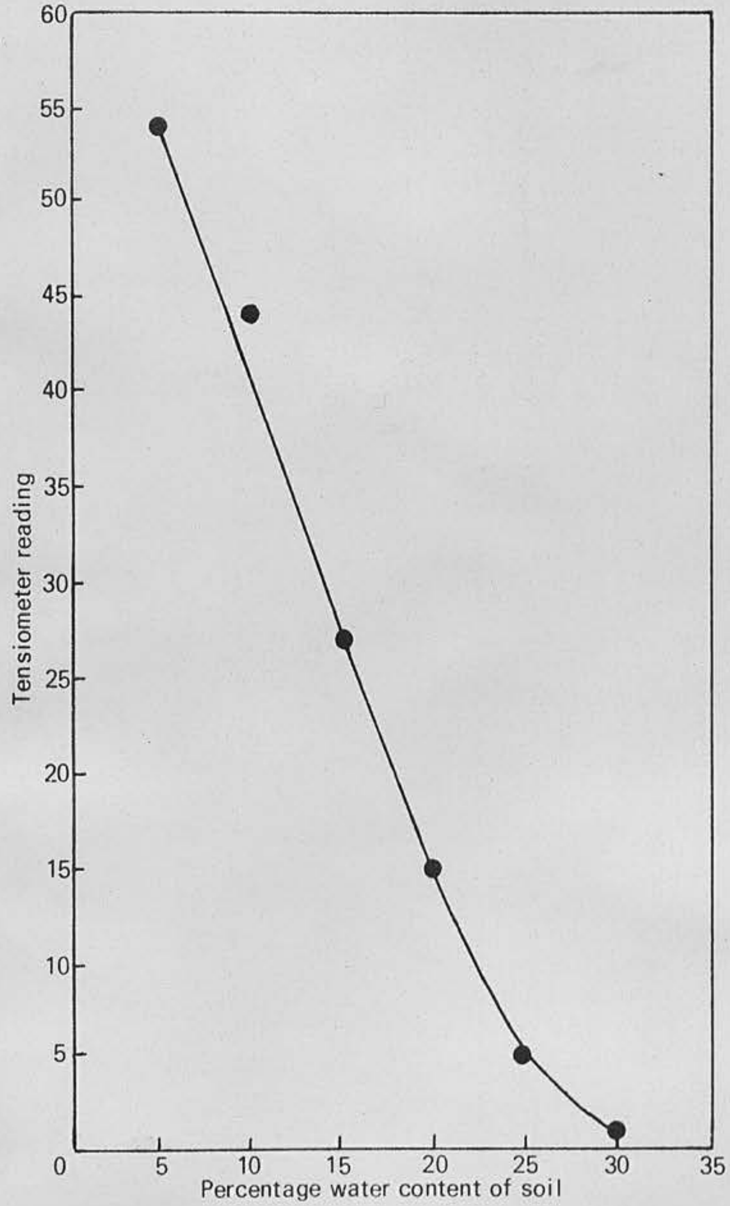


Fig 2A The constructed soil moisture curve for the soil of the grass plot at Bush

Plate 1A The sampling grid containing a soil sample

Plate 2A Method of taking a plant-soil sample from the ridge of a potato crop

Discussion

The numbers of introduced slugs and eggs recovered from ten soil samples by the standard soil-washing recovery method show that the method was very efficient for adult and young slugs of the three species and the eggs of A. reticulatus and A. fasciatus. The low recovery of the eggs of A. hortensis is in agreement with the observations of Hunter who also found that the friable eggs of this species tend to be broken up by water jets.

The recovery efficiency obtained by the progressive flooding technique was somewhat better than that obtained by South and Hunter and as good as that by the standard soil wash method. It was also a quicker operation taking 2-4 days instead of 5-6 days. In many cases slugs were successfully recovered within 48 hours from arable samples flooded in the larger containers.

The recovery efficiency of the progressive heat treatment for two turf samples was only slightly less than that for flooding, however, the lower recovery from the one arable sample indicates that further refinements are necessary to successfully extract slugs from such samples by this method. This method has the great advantage of extracting slugs very quickly (4-6 hours) from a large number of sample units simultaneously.

Appendix B

Table 1B

Estimates of the population density of adult A. reticulatus on the grass plot at Bush from routine monthly turf samples

Monthly Sample	Mean number per sq.ft. + fiducial intervals at the 95% confidence level			% estimate of the mean	Equivalent Number per acre (X 10^3)		
1967							
March	10.6	±	3.5	33	462.6	±	152.5
April	8.5	±	3.6	43	370.3	±	155.8
May	8.8	±	2.5	29	381.2	±	109.7
June	4.8	±	2.4	48	206.9	±	102.9
July	5.6	±	1.9	35	245.0	±	82.4
August	4.5	±	2.9	60	196.0	±	116.8
September	2.5	±	1.7	66	108.9	±	72.2
October	5.0	±	1.1	21	217.8	±	45.1
November	4.4	±	0.4	10	192.4	±	18.3
December	9.6	±	3.9	39	419.2	±	168.9
1968							
January	7.4	±	2.8	38	321.3	±	121.9
February	10.0	±	3.2	32	435.6	±	140.8
March	7.9	±	4.1	50	343.1	±	177.3
April	6.3	±	3.3	54	272.3	±	145.1
May	7.3	±	2.3	31	315.8	±	98.0
June	3.1	±	2.5	78	136.2	±	108.4
July	2.9	±	1.2	64	125.3	±	52.2

Table 2B

Estimates of the population density of adult A. hortensis on the grass plot at Bush from routine monthly turf samples

Monthly Sample	Mean number per sq.ft. + fiducial intervals at the 95% confidence level			% estimate of the mean	Equivalent Number per acre (X 10^3)		
1967							
March	8.0	±	3.6	45	348.5	±	155.3
April	7.8	±	3.6	46	337.6	±	154.2
May	5.0	±	2.4	48	217.8	±	103.8
June	5.3	±	2.7	51	228.7	±	117.3
July	0.8	±	0.9	126	32.7	±	41.2
August	2.4	±	1.1	65	102.9	±	45.5
September	1.6	±	1.1	45	69.7	±	45.5
October	2.8	±	1.5	53	119.8	±	63.2
November	3.0	±	0.5	16	130.7	±	20.8
December	3.6	±	3.2	89	157.9	±	141.9
1968							
January	2.0	±	2.5	123	87.1	±	107.2
February	2.3	±	1.2	52	98.0	±	50.5
March	2.5	±	2.2	87	108.9	±	95.0
April	5.5	±	1.6	29	239.6	±	691.7
May	4.0	±	1.8	45	174.2	±	77.8
June	2.1	±	3.8	177	92.5	±	164.7
July	0.8	±	0.8	100	32.7	±	33.3

Table 3B

Estimates of the population density of adult A. fasciatus on the grass plot at Bush from routine monthly turf samples

Monthly Sample	Mean number per sq.ft. + fiducial intervals at the 95% confidence level			% estimate of the mean	Equivalent Number per acre (X 10^3)		
1967							
March	3.8	±	0.9	26	163.4	±	42.9
April	3.4	±	1.6	48	145.9	±	69.5
May	2.8	±	1.3	48	119.8	±	56.9
June	1.9	±	3.6	193	81.6	±	158.2
July	1.0	±	0.7	67	43.6	±	29.4
August	0.0	±	0.0	0	0.0	±	0.0
September	0.1	±	0.4	38	5.4	±	16.6
October	0.3	±	0.4	194	10.9	±	15.8
November	1.3	±	0.4	30	55.8	±	16.8
December	1.3	±	0.8	61	54.5	±	33.2
1968							
January	1.5	±	1.7	111	65.3	±	72.4
February	2.4	±	0.3	13	103.4	±	13.7
March	1.4	±	1.7	120	59.9	±	72.4
April	1.6	±	1.5	94	69.8	±	65.7
May	3.0	±	1.3	41	130.7	±	54.1
June	1.3	±	0.5	40	54.5	±	21.9
July	0.9	±	0.9	98	38.1	±	37.3

Table 4B

Estimates of the population density of adult slugs of the 3 species on the grass plot from routine monthly turf samples

Monthly Sample	Mean number per sq.ft. + fiducial intervals at the 95% confidence level			% estimate of the mean	Equivalent Number per acre ($X 10^3$)		
1967							
March	22.1	±	5.5	25	963.1	±	236.9
April	19.9	±	6.6	30	865.1	±	285.8
May	16.4	±	16.1	19	712.6	±	702.2
June	11.9	±	4.8	41	516.6	±	209.3
July	7.4	±	0.6	8	320.6	±	23.9
August	6.9	±	3.6	52	298.8	±	154.0
September	4.3	±	2.5	59	184.7	±	108.3
October	8.0	±	2.5	31	348.5	±	107.3
November	9.0	±	2.2	24	392.0	±	95.0
December	14.5	±	6.1	42	631.6	±	266.4
1968							
January	10.9	±	5.8	53	473.1	±	252.5
February	15.0	±	4.5	30	653.4	±	196.5
March	11.8	±	6.9	58	511.4	±	298.7
April	12.6	±	4.6	36	559.7	±	198.3
May	14.9	±	3.5	24	647.3	±	151.9
June	6.5	±	3.2	49	283.1	±	139.0
July	3.1	±	1.6	49	135.9	±	67.0

Table 5B

Estimates of the population density of adult slugs on ploughed stubble and a grass paddock - Beanston

Site	Slug species	Mean density per sq.ft. with fiducial limit at 95% confidence level	% estimate of the Mean	Equivalent Number per Acre ($X10^3$)
1) Ploughed field	A.reticulatus	3.0 ± 0.9	33	130.7 ± 39.2
	A.hortensis	1.7 ± 1.0	59	74.1 ± 43.5
	A. fasciatus	0.2 ± 0.6	300	8.7 ± 26.1
	Total	4.9 ± 1.7	35	213.5 ± 74.1
2) Paddock	A.reticulatus	2.2 ± 1.4	64	95.8 ± 61.0
	A.intermedius (total)	7.2 ± 3.4	47	313.6 ± 148.1
	A. fasciatus	0.1 ± 1.8	556	1.5 ± 78.4
	Total	9.4 ± 2.8	30	409.5 ± 121.4

Table 6B

Estimates of the slug population density adjacent to the tubers in four potato crops

	Mean density per sq.ft.			% estimate of the mean			Equivalent number per acre x 10^3		
Slug Species :-	R	H	F	R	H	F	A. reticulatus	A. hortensis	A. fasciatus
1. Redskin crop. Beanston	1.3	3.9	0.1	69	56	219	54.5 ± 37.4	168.9 ± 95.1	5.4 ± 115.5
Total of 3 species		5.4			54			234.1 ± 127.1	
2. Variety trial. Beanston	0.7	1.4	0.2	83	66	193	31.5 ± 26.0	59.5 ± 39.6	7.3 ± 1.4
Total of 3 species		2.2			55			96.8 ± 53.2	
3. Variety trial. Langhill	1.5	0.4	0.8	40	113	51	64.6 ± 25.7	15.0 ± 16.9	34.5 ± 17.6
Total of 3 species		2.6			30			114.2 ± 34.3	
4. Variety trial. Gateside									
Sample i)	2.9	6.1	1.0	28	30	55	128.8 ± 35.8	267.0 ± 79.9	45.5 ± 25.3
Total of 3 species		10.1			18			413.8 ± 72.7	
Sample ii)	3.1	4.8	1.5	40	36	41	154.8 ± 53.9	210.5 ± 76.1	62.9 ± 25.6
Total of 3 species		10.1			70			440.8 ± 311.0	

Table 7B

Estimates of slug population density made by other authors

Author	Field-site-crop	Method of sampling	Slug species	Density per acre x 10^3
Carrick (1936)	Rye grass field	Copper sulphate - broadcast	A.reticulatus	48.4
Thomas (1944)	Young wheat crop	meta-baits	A.reticulatus	600.0
South (1965)	Grassland	soil samples	A.reticulatus	87.1 ± 24.0
	same site	surface searched quadrats	A.reticulatus	25.3 ± 8.7
	Parkland	" "	A.reticulatus	243.9
Hunter (1966)	Grass plot	soil sample	A.reticulatus	17.4 -422.5
			A.hortensis	52.3 -339.8
	Potato plot	soil sample 1963	A.reticulatus	759.7 ± 308.4
			A.hortensis	304.9 ± 117.6
		soil sample 1964	A.reticulatus	311.5 ± 120.6
			A.hortensis	64.0 ± 57.5
Newell (1965)	Undersown stubble	mark, release and recapture	A.reticulatus	10.0 ± 25.0
	" "	" " "	A.reticulatus	72.0 ± 25.0

APPENDIX C

Supplementary data on potato varietal differences by other workers

Table 1C

Difference in the periderm thickness and crude fibre content of five varieties of potatoes

(E. Nagdy Ph.D. thesis)

Potato variety	Periderm thickness (µ)	Percentage crude fibre
Redskin	103.7	28.8
K. Pink	94.9	25.1
K. Edward	91.0	23.6
G. Wonder	158.8	31.9
Majestic	105.7	28.4

Table 2C

Mean of 25 Lampé readings from penetrometer tests

on 25 potato tubers

(made by the N.I.A.E. at the Edinburgh Centre of Rural Economy)

Variety	1965	1966	1967	Mean
Redskin	34.9	33.1	29.4	32.5
K. Pink	31.4	32.3	29.6	31.1
K. Edward	35.5	32.1	33.1	33.6
G. Wonder	35.6	42.1	31.7	36.5
Majestic	30.3	29.6	28.8	29.6
P. Dell	31.5	36.5	30.8	32.9

Table 3C

Varietal differences in the magnitude of sweetening during storage at 10°C

(W.G. Burton 1965)

Variety	Sugar content 1 week after harvest mg/100 g fresh weight		
	Total	Reducing	Non-reducing
K. Edward	0.14	0.06	0.08
Majestic	0.38	0.23	0.13
G. Wonder	0.39	0.13	0.26

APPENDIX D

Table 1D

Slug damage in sample 1 (4th September) from the early versus late haulm removal trial

Damage - Plot No.		Control	Treated	Difference
% Tuber Damage	1	22.87	16.32	+6.55
	2	6.55	12.79	-6.24
	3	17.66	15.34	+2.32
	4	21.05	20.79	+0.26
	5	10.78	12.79	-2.07
	6	18.53	12.66	+5.87
	7	18.53	16.32	+2.21
	8	20.27	9.10	+11.17
		Value of t = 1.32 - NS		
Number of Holes	1	1.38	1.00	+0.38
	2	0.60	0.90	-0.30
	3	1.20	1.11	+0.09
	4	1.42	1.48	-0.06
	5	1.00	0.60	+0.40
	6	1.28	0.78	+0.50
	7	1.20	1.28	-0.07
	8	1.32	0.60	+0.72
		Value of t = 1.69 - NS		
% Plant Damage	1	56.79	39.23	+17.56
	2	18.44	33.21	-14.77
	3	45.00	45.00	-
	4	45.00	50.77	- 5.77
	5	33.21	33.21	-
	6	50.77	33.21	+17.56
	7	50.77	45.00	+ 5.77
	8	45.00	26.56	+18.44
		Value of t = 1.12 - NS		

Table 2D

Slug damage in sample 2 (13th September) from the early versus late haulm removal trial

Damage -Plot No.	Control	Treated	Difference
% Tuber Damage 1	16.64	25.03	-8.39
2	19.28	17.36	+1.92
3	12.79	13.05	-0.26
4	20.18	25.77	-5.59
5	17.46	23.89	-6.43
6	12.25	20.53	-8.28
7	15.79	17.85	-2.06
8	8.91	17.16	-8.25
	Value of t = 3.29 *		
Number of Holes 1	1.08	1.38	-0.30
2	1.38	1.18	+0.20
3	1.00	0.70	+0.30
4	1.08	1.04	+0.04
5	1.00	1.34	-0.34
6	1.18	1.43	-0.26
7	1.00	1.20	-0.20
8	0.48	0.90	-0.43
	Value of t = 1.29 NS		
% Plant Damage 1	45.00	56.79	-11.79
2	50.77	45.00	+ 5.77
3	26.56	39.23	-12.67
4	45.00	45.00	-
5	39.23	63.44	-24.21
6	39.23	50.77	-11.54
7	39.23	50.77	-11.54
8	18.44	39.23	-20.79
	Value of t = 3.12 *		

Table 3D

Slug damage in sample 3 (24th September) from the early versus late haulm removal trial

Damage - Plot No.	Control	Treated	Difference
% Tuber Damage 1	18.24	27.28	-9.04
2	20.09	16.85	+3.24
3	19.37	18.63	+0.74
4	28.25	22.63	+5.62
5	32.96	28.25	+4.71
6	16.11	14.54	+1.57
7	21.64	16.95	+4.69
8	18.53	20.88	-2.35
	Value of t = 0.67 NS		
Number of Holes 1	1.18	1.62	-0.45
2	1.46	1.28	-0.18
3	1.18	1.18	-
4	1.46	1.38	+0.08
5	1.81	1.43	+0.38
6	1.18	0.90	+0.27
7	1.34	1.18	+0.17
8	1.42	1.48	-0.06
	Value of t = 0.81 NS		
% Plant Damage 1	50.77	18.44	+32.33
2	50.77	33.21	+17.56
3	50.77	39.23	+11.54
4	56.79	50.77	+ 6.02
5	63.44	56.79	+ 6.65
6	45.00	39.23	+ 5.77
7	63.44	45.00	+18.44
8	45.00	45.00	-
	Value of t = 3.40 *		

Table 4D

Slug damage in sample 4 (3rd October) from the early versus late haulm removal trial

Damage - Plot No.	Control	Treated	Difference
% Tuber Damage 1	25.92	23.34	+2.58
2	18.05	10.78	+7.27
3	12.92	17.76	-4.84
4	25.48	27.35	-1.87
5	21.64	20.96	+0.68
6	18.63	16.54	+2.09
7	20.36	18.53	+1.83
8	22.38	20.36	+2.02
	Value of t = 0.98 NS		
Number of Holes 1	1.26	1.38	-0.12
2	1.11	0.90	+0.21
3	1.04	1.08	-0.04
4	1.54	1.36	+0.18
5	1.15	1.56	-0.41
6	1.18	1.26	-0.08
7	1.30	1.36	-0.06
8	1.23	1.62	-0.39
	Value of t = 1.11 NS		
% plant Damage 1	45.00	63.44	-18.44
2	45.00	18.44	+26.56
3	39.23	45.00	- 5.77
4	63.44	71.56	- 8.12
5	45.00	39.23	+ 5.77
6	56.79	33.21	+23.58
7	50.77	39.23	+11.54
8	56.79	39.23	+17.56
	Value of t = 1.14 NS		

Table 5D

Slug damage in sample 5 (11th October) from the early versus late haulm removal trial

Damage - Plot No.	Control	Treated	Difference
% Tuber Damage 1	32.01	38.53	-6.52
2	11.54	13.69	-2.15
3	24.58	21.13	+3.45
4	27.83	23.03	+4.80
5	25.70	23.81	+1.89
6	20.44	27.76	-7.32
7	23.58	28.45	-4.87
8	17.05	22.38	-5.33
	Value of t = 1.19 NS		
Number of Holes 1	1.60	1.90	-0.30
2	0.70	1.00	-0.30
3	1.36	1.40	-0.04
4	1.42	1.26	+0.16
5	1.71	1.40	+0.31
6	1.34	1.51	-0.16
7	1.48	1.52	-0.04
8	1.08	1.26	-0.14
	Value of t = 1.11 NS		
% Plant Damage 1	71.56	90.00	-18.44
2	39.23	45.00	- 5.77
3	71.56	56.79	+14.77
4	56.79	50.77	+ 6.02
5	50.77	50.77	-
6	63.44	50.77	+12.67
7	50.77	63.44	-12.67
8	50.77	45.00	+ 5.77
	Value of t = 0.07 NS		

APPENDIX E

Table 1E

Adult slug counts on three pellet strips - Gullane

Slug Species Date of catch	Position of pellet strip		
	1 (adjacent to hedge)	2 (mid field)	3 (mid field)
16th August,1966			
A. reticulatus	551	22	13
A. fasciatus	18	62	10
17th August,1966			
A. reticulatus	139	4	10
A. fasciatus	5	12	19
25th August,1966			
A. reticulatus	75	3	9
A. fasciatus	0	3	9
5th Sept. 1966			
A. reticulatus	71	10	43
A. fasciatus	0	6	52